Journal: *Atmospheric Chemistry and Physics*

MS Title: Urban Aerosol Size Distributions: A Global Perspective

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MS No.: acp-2020-92

MS Type: Review Article

We would like to thank the two reviewers for their insightful comments and helpful feedback. We have revised our manuscript, as outlined below. Comments from the reviewers are in italic black font. Our responses are in normal black font. Revised text are in normal red font. Revised figures and tables are included.

Response to Anonymous Referee #2

I commend the authors for attempting this expansive review, which will be very helpful to the aerosol community. I apologize for not submitting a review in time, and even now my work is incomplete. Normally, I spend a couple of hours on a review; I have spent well over that on this manuscript and I am still less than a third of the way through it.

Some of that is apparently because of ACP's format requirements - with 25 figures at the end, reading and relating discussions to figures becomes very difficult. For what it's worth, the comments I have so far are mostly grammatical or ways to frame it better.

Some general comments:

1. This review attempts to not only review worldwide PSDs, but also applications in exposure and filtration. The latter two are fields in their own right for good reason and should perhaps be separated as a companion paper (or papers) that can be reviewed by experts in those fields. 2. Perhaps this expansive work is better as a monograph that can be fact-checked, verified, and copy-edited by paid staff, or at least split into three or four papers, with measurement experts, atmospheric chemists, inhalation modelers, and building/indoor air quality experts reviewing the different parts. The latter might also make it easier for an individual reviewer to spend a few hours and do a satisfactory job within their expertise.

Response: We understand that this review is very long with nearly 30 figures. One of the most important reasons that we chose to submit our review to ACP is that it is a high-quality, open-access, interdisciplinary journal without word/page limits. It has a broad audience interested in atmospheric science, air quality, climate, and human health impacts. This long review allows readers with different backgrounds to retrieve the relevant information they need, but not necessarily having to read the entire paper. We feel that the geographical variations in urban PSDs provides important implications for human exposure and indoor air quality, which may be of interest to many readers. Therefore, we think it is logical to discuss these topics in one paper. In addition, expansive and lengthy reviews have been published in ACP in the past, such as Fuzzi et al. (2015), Lawrence and Lelieveld (2010), Kukkonen et al. (2012), Bartels-Rausch et al. (2014), Vihma et al. (2014), and Tang et al. (2019).

3. One of my comments was whether 1 nm species can even be called aerosol particles, and that seems a definitional rabbit hole. If one were to focus on urban air quality and exposure/HVAC applications, the sub-10 nm aerosols may not even be practically relevant or can be left for another paper.

Response: Although previous papers referred to the species between 1-3 nm as nanocluster aerosols, here we would not like to debate if they are aerosol particles. 'a diverse mixture of liquid and solid particles spanning in size from a single nanometer to tens of micrometers' has been changed to 'a diverse mixture of liquid and solid particles spanning in size from several nanometers to tens of micrometers'.

Specific comments: Abstract, line 3: replace "enable for characterization" with "enable characterization"

Response: This has been changed.

Introduction, line 2/para 1: "spanning in size from a single nanometer to tens of micrometers" - can 1 nm actually be considered an aerosol particle? Seems like an issue of definition - has previous work established a lower size limit for the transition from molecules to aerosol particles? (The authors limit their own review to aerosol sizes above 3 nm.)

Response: 'spanning in size from a single nanometer to tens of micrometers' has been changed to 'spanning in size from several nanometers to tens of micrometers'.

Introduction, para 2: "Measurement of urban aerosol PSDs provides. . ." and "UFPs...are associated with various deleterious human health outcomes." These statements should be backed up by references to epidemiological and toxicological studies, especially as the paragraph criticizes current air quality standards that are based on PM mass (and which have been quite effective at improving human health). A problem could very well be (as the authors state) that most PSD measurements are not longterm, which is necessary for epidemiological studies; but that surely is the end product of the current manuscript (e.g. "we recommend more long-term studies") rather than a declarative statement at the outset. Toxicological studies do not require long-term studies; the authors should be able to cite studies that back up their claims.

Response: References have been added to para. 2 to support the claims.

'Of particular importance are measurements of urban aerosol particle size distributions (PSDs). Measurement of urban aerosol PSDs provides a basis for in-depth evaluation of size-resolved aerosol transport and transformation processes in the urban atmosphere (e.g. Hussein et al., 2004; Peng et al., 2014; Salma et al., 2011; Wehner et al., 2008; Wu et al., 2008), air pollution source apportionment (e.g. Harrison et al., 2011; Sowlat et al., 2016; Wang et al., 2013b), aerosol deposition in the human respiratory system (e.g. Hussein et al., 2019, 2020; Kodros et al., 2018; Zwozdziak et al., 2017), and associated toxicological effects on the human body (e.g. Bentayeb et al., 2015; Burnett et al., 2014; Oberdürster, 2000; Shiraiwa et al., 2017; Tseng et al., 2015; Wong et al., 2015). In addition, the measurement of aerosol PSD is important for evaluating the global climate change, since aerosol size strongly affects the interaction of aerosol with radiation and its ability to form fog and cloud droplets (Mahowald, 2011; Seinfeld and Pandis, 2012; Zhang et al., 2012). Despite the atmospheric and health relevance of urban PSDs, long-term aerosol measurements are often focused on size-integrated concentration metrics, such as PM2.5, that lack essential size-resolved information. While urban aerosol PSD measurements have been conducted in cities around the globe, they are often short in duration and not performed as part of routine air quality monitoring. Urban PSDs provide a more complete assessment of an aerosol population, beyond what can be achieved with size-integrated metrics. Of particular importance are urban PSDs that capture the ultrafine particle regime (UFP, 1 to 100 nm). UFPs tend to dominate number PSDs, penetrate deep into the lung, and are associated with various deleterious human health outcomes (Allen et al., 2017; Delfino et al., 2005; Jiang et al., 2009; Li et al., 2016, 2017a; Oberdörster, 2001; Oberdörster et al., 2004, 2005; Rychlik et al., 2019; Sioutas et al., 2005; Weichenthal et al., 2017).'

Introduction/last paragraph: replace "enables for identification of gaps" with "enables identification of gaps" (Please check the manuscript for similar language corrections, I will stop now.) Also, the authors should probably state in the introduction that their 3 nm to 10 micron size range refers to electrical mobility diameter.

Response: The language has been corrected. Clarification has been made: '3 to 10,000 nm as electrical mobility diameter'.

Methodology: What is the time duration of an individual PSD? Typical SMPS scans are 2 minutes; optical sizing can be at 1 Hz. Or do they mean 793 measurement campaigns or days of data?

Response: The time duration of each individual PSD has been listed in the SI. Given the great uncertainty of instantaneous snapshots, the PSDs and size-resolved ρ_{eff} collected in this study are all time-average results over a given sampling period. The following sentences have been added to Section 2 and Section 3.2:

'These articles presented n=793 individual PSDs (182 of which covered both the sub-micron and coarse regime), which have been reported in previous peer-review journal articles in the form of figures or fitting parameters'; 'All the PSDs are the results of a time-average over certain sampling periods'.

Abbreviations for geographical regions: I had a hard time remembering what each stood for, e.g. CSSA or WA. Suggest the use of Africa, EAsia, WAsia, CSSAsia, etc. Why is the EU separated from North America/Australia/New Zealand - these are all OECD regions with greater similarities in emissions control regimes compared to Asia or Africa.

Response: A list of symbols and abbreviations has been added to Appendix A, which could help the readers to identify the abbreviations for geographical regions more easily.

Appendix A: List of symbols and abbreviations.

Table A1. List of symbols and abbreviations.

AF	Africa	D_{em}	Electrical mobility diameter
APM	Aerosol particle mass analyzer	D_a	Aerodynamic diameter
APS	Aerodynamic Particle Sizer	D_{op}	Optical diameter
CC	City center	D_{ve}	Volume equivalent diamter
CMD	Count median diameter	ρ_{eff}	Aerosol effective density
CSSA	Central, South, and Southeast Asia	ρ_p	Aerosol particle density
DMA	Differential mobility analyzer	χ	Dynamic shape factor
EA	East Asia	m_p	Particle mass
ELVOC	Extremely low volatility organic compound	Vp	Particle volume
EU	Europe	C_c	Cunningham slip correction factore
HOM	Highly oxygenated molecule	N_i	Particle number concentration for mode *i*
HVAC	Heating, ventilation, and air-conditioning	$\overline{D_{p,i}}$	Geometric mean diameter for mode *i*
LA	Latin America	σ_i	Geometric standard deviation for mode *i*
LT	Long term (>6 months)	V_i	Particle volume concentration for mode *i*
MERV	Minimum efficiency reporting value	M_i	Particle mass concentration for mode *i*
MOUDI	Micro-orifice uniform deposit impactor	V_T	Tidal volume
MPPD	Multiple-Path Particle Dosimetry	f	Breathing frequency
MT	Moderate term (1 - 6 months)	DF	Deposition fraction
NAAN	North America, Australia, and New Zealand		
NPF	New particle formation		
NU	Non-specific urban		
OPC/OPS	Optical particle counter/Optical particle sizer		

PM_X	Integrated mass concentration for particles smaller than X µm
PSD	Particle size distribution
RTDDR	Respiratory tract deposited dose rate
SMPS	Scanning Mobility Particle Sizer
SOA	Secondary organic aerosol
ST	Short term (1 week – 1 month)
SUB	Sub-urban
TR	Traffic-influenced
UB	Urban background
UFP	Ultrafine particle (<100 nm)
VOC	Volatile organic compound
VST	Very short term (1 day – 1 week)
VVST	Very very short term (<1 day)
WA	West Asia

We would like to group the PSDs according to geographical regions to investigate the spatial variations in PSDs, therefore we separated EU from North America. In the early stages of our analysis, we grouped Australia and New Zealand as Oceania, separately from North America. However, the sample size of Oceania is too small for conducting a meaningful analysis. Therefore, we grouped Australia and New Zealand with North America, rather than Europe, since their population density is closer to North America.

Figure 9 is introduced and discussed before Figure 2. Suggest re-ordering the figures in the order they are discussed.

Response: The figures have been re-ordered.

Section 3.4: what did Rissler et al. report as density for soot aggregates - that seems relevant for group C (traffic environments) if EC can be a quarter of particle mass. A statement about the material density of soot appears at the end of the first paragraph of Sec 3.5 - which is supposed to be about coarse particles that likely don't have a lot of EC. Perhaps that should be moved to Sec 3.4. The last sentence seems unclear - if both soot particles and denser(?) components can exist in the 400-1000 nm size range, why pick one over the other unless one component dominates the mass?

Response: Direct measurements of effective density are missing for the particles between 400-1000 nm. The measurements in Rissler et al. (2014) are from 50 to 350 nm. Since at 350 nm, dense particles contributed more than 80% to the total particle mass in Rissler et al. (2014), the effective density of dense mode particles (1.46 g cm^{-3}) was chosen for the size range of 400-1000 nm. In addition, the HR-AMS analysis in Rissler et al. (2014) indicated that the dense mode particles were made of ammonium nitrate, ammonium sulfate, and organic carbon. Although soot particles also exist in the size range of 400-1000 nm, the fraction of particles with greater effective densities than the dense mode particles, such as crustal materials, could be higher (Daher et al., 2013) than in the size range of 50-350 nm, which to some extent offsets the low density of soot particles.

The sentence, 'The inherent material density of diesel soot was measured to be 1.77 g cm^{-3} (Park et al., 2004)', has been removed.

References:

Bartels-Rausch, T., Jacobi, H.-W., Kahan, T. F., Thomas, J. L., Thomson, E. S., Abbatt, J. P., Ammann, M., Blackford, J. R., Bluhm, H. and Boxe, C.: A review of air–ice chemical and physical interactions (AICI): liquids, quasi-liquids, and solids in snow, Atmos. Chem. Phys., 14(3), 2014.

Brines, M., Dall'Osto, M., Beddows, D. C. S., Harrison, R. M., Gómez-Moreno, F., Núñez, L., Artíñano, B., Costabile, F., Gobbi, G. P. and Salimi, F.: Traffic and nucleation events as main sources of ultrafine particles in high-insolation developed world cities, Atmos. Chem. Phys., 15(10), 5929–5945, 2015.

Daher, N., Saliba, N. A., Shihadeh, A. L., Jaafar, M., Baalbaki, R. and Sioutas, C.: Chemical composition of size-resolved particulate matter at near- freeway and urban background sites in the greater Beirut area, , 80, 96–106, 2013.

Fuzzi, S., Baltensperger, U., Carslaw, K., Decesari, S., Denier Van Der Gon, H., Facchini, M. C., Fowler, D., Koren, I., Langford, B., Lohmann, U., Nemitz, E., Pandis, S., Riipinen, I., Rudich, Y., Schaap, M., Slowik, J. G., Spracklen, D. V., Vignati, E., Wild, M., Williams, M. and Gilardoni, S.: Particulate matter, air quality and climate: Lessons learned and future needs, Atmos. Chem. Phys., 15(14), 8217–8299, doi:10.5194/acp-15-8217-2015, 2015.

Kukkonen, J., Olsson, T., Schultz, D. M., Baklanov, A., Klein, T., Miranda, A. I., Monteiro, A., Hirtl, M., Tarvainen, V. and Boy, M.: A review of operational, regional-scale, chemical weather forecasting models in Europe, Atmos. Chem. Phys., 2012.

Lawrence, M. G. and Lelieveld, J.: Atmospheric pollutant outflow from southern Asia: a review, Atmos. Chem. Phys., 10(22), 11017, 2010.

Tang, M. J., Chan, C. K., Li, Y. J., Su, H., Ma, Q. X., Wu, Z. J., Zhang, G. H., Wang, Z., Ge, M. F. and Hu, M.: A review of experimental techniques for aerosol hygroscopicity studies, Atmos. Chem. Phys., 2019.

Vihma, T., Pirazzini, R., Fer, I., Renfrew, I. A., Sedlar, J., Tjernstrom, M., Lüpkes, C., Nygard, T., Notz, D. and Weiss, J.: Advances in understanding and parameterization of small-scale physical processes in the marine Arctic climate system: a review, Atmos. Chem. Phys., 14(17), 9403–9450, 2014.

Additional changes:

1. The table of "List of the number of urban PSDs that have been extracted and analyzed in each region, country, and city" has been corrected.

Table 1. List of the number of urban PSDs that have been extracted and analyzed in each region, country, and city.

Region	**Country**	**City**
Africa (*n*=29)	Botswana (3)	Gaborone (3)
	Cape Verde (1)	Praia City (1)
	Egypt (12)	Cairo (12)
	Kenya (1)	Nairobi (1)
	Mali (1)	Bamako (1)
	Senegal (1)	Dakar (1)
	South Africa (6)	Johannesburg (2)
		Pretoria (4)
	Zambia (4)	Mongu (4)
	India (48)	Durg (4)

Central, South, and Southeast Asia (n=70)		Kanpur (23)
		Mumbai (2)
		New Delhi (13)
		Pune (2)
		Trivandrum (4)
	Nepal (4)	Lalitpur (1)
		Dhulikhel (3)
	Pakistan (8)	Karachi (3)
		Lahore (3)
		Peshawar (1)
		Rawalpindi (1)
	Singapore (6)	Singapore City (6)
	Thailand (2)	Chiang Mai (1)
		Silpakorn (1)
	Vietnam (2)	Ho Chi Minh (2)
East Asia (n=138)	China (93)	Beijing (38)
		Guangzhou (14)
		Hong Kong (6)
		Jinan (1)
		Jinhua (1)
		Lanzhou (11)
		Nanjing (2)
		Shanghai (12)
		Shenzhen (3)
		Zhengzhou (2)
		Urumchi (1)
		Wuxi (2)
	Japan (17)	Kawasaki (10)
		Sapporo (6)
		Tokyo (1)
	South Korea (24)	Gwangju (16)
		Seoul (4)
		Ulsan (4)
	China: Taiwan (4)	Taipei (3)
		Taichung (1)
Europe (n=316)	Austria (7)	Vienna (7)
	Belgium (1)	Gent (1)
	Switzerland (4)	Zurich (4)
	Czech Republic (4)	Prague (4)
	Germany (68)	Aachen (1)
		Augsburg (2)

		Braunschweig (12)
		Dresden (4)
		Duisburg (1)
		Erfurt (9)
		Essen (5)
		Heidelberg (2)
		Karlsruhe (5)
		Leipzig (27)
	Denmark (26)	Copenhagen (25)
		Odense (1)
	Spain (17)	Barcelona (7)
		Ciudad Real (2)
		Madrid (8)
	Finland (52)	Helsinki (52)
	France (10)	Marseilles (5)
		Paris (3)
		Dunkirk (2)
	United Kingdom (37)	Birmingham (1)
		Cambridge (7)
		Leeds (3)
		Leicester (2)
		London (19)
		Manchester (5)
	Greece (7)	Athens (3)
		Chania (4)
Europe (n=316)	Hungary (9)	Budapest (9)
	Italy (31)	Bologna (2)
		Cagliari (1)
		Cassino (2)
		Ispra (4)
		Milan (15)
		Rome (7)
	Lithuania (9)	Vilnius (9)
	Netherland (6)	Amsterdam (4)
		Rotterdam (2)
	Norway (3)	Oslo (3)
	Portugal (12)	Oporto (10)
		Lisbon (2)
	Russia (1)	Tiksi (1)
	Sweden (11)	Gothenburg (3)

		Stockholm (8)
	Moldova (1)	Chisinau (1)
Latin America (*n*=48)	Brazil (38)	Porto Alegre (3)
		São Paulo (35)
	Chile (6)	Santiago (6)
	Mexico (3)	Mexico City (3)
	Cuba (1)	Camagüey (1)
North America, Australia and New Zealand (*n*=134)	Australia (10)	Brisbane (2)
		Launceston (7)
		Wollongong (1)
	New Zealand (8)	Auckland (8)
	Canada (15)	Hamilton (2)
		Toronto (13)
North America, Australia and New Zealand (*n*=134)	United States (U.S.) (101)	Atlanta (4)
		Boulder (1)
		Buffalo (6)
		Claremont (5)
		Corpus Christi (4)
		Detroit (6)
		Downey (4)
		Fresno (12)
		Houston (1)
		Los Angeles (34)
		New York (5)
		Newark (2)
		Pittsburgh (7)
		Raleigh (1)
		Riverside (8)
		Rochester (1)
West Asia (*n*=58)	Iran (23)	Zanjan (23)
	Jordan (1)	NA
	Kuwait (12)	Fahaheel (12)
	Saudi Arabia (9)	Yanbu (9)
	Turkey (13)	Istanbul (13)

2. A paragraph of discussion on the influence of environmental factors in different geographical locations on filter performance has been added to Section 10.

'In addition, different geographical locations may result in different environmental factors, which can influence the performance of a filter. For example, the dendrites of the deposited particles may experience more frequent collapse in geographical regions with annual rainy seasons when the relative humidity increases significantly. The dendrites may restructure to adopt a compact morphology under elevated humidity due to the capillary effect of condensed water, which will lower the filtration efficiency and pressure drop across the filter (Pei et al., 2019). In addition, the hygroscopic content of the dendrites may transition to form a liquid film on the filter fiber, and decrease the filtration efficiency before eventually reaching an equilibrium (Li et al., 2014; Walsh et al., 1996). This is attributes to the low viscosity of the liquid film, which allows the liquid particles to coalesce, relocate, and drain along the filter fiber.'

3. Errors in some figures have been corrected. Order of the figures has been rearranged.

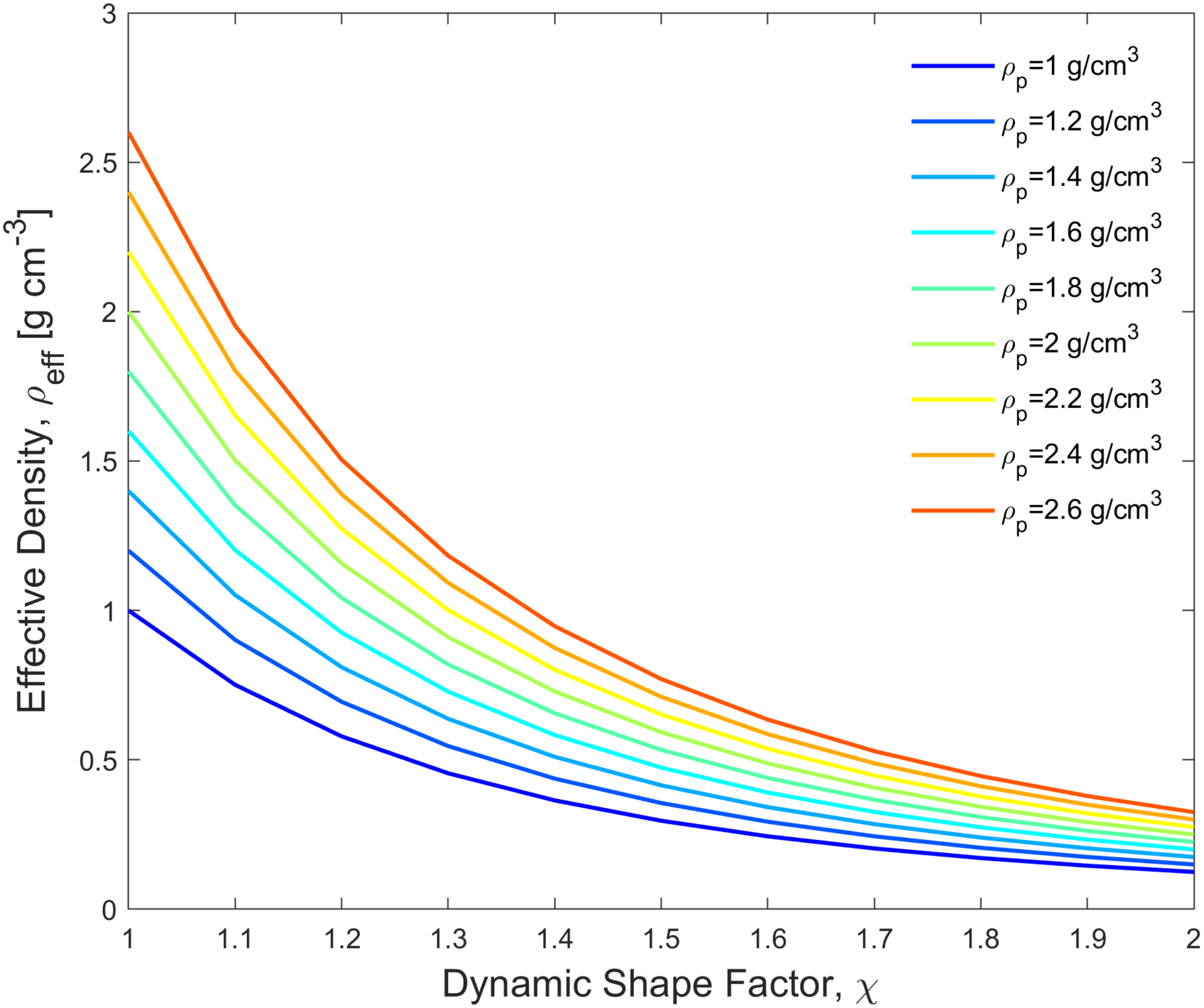
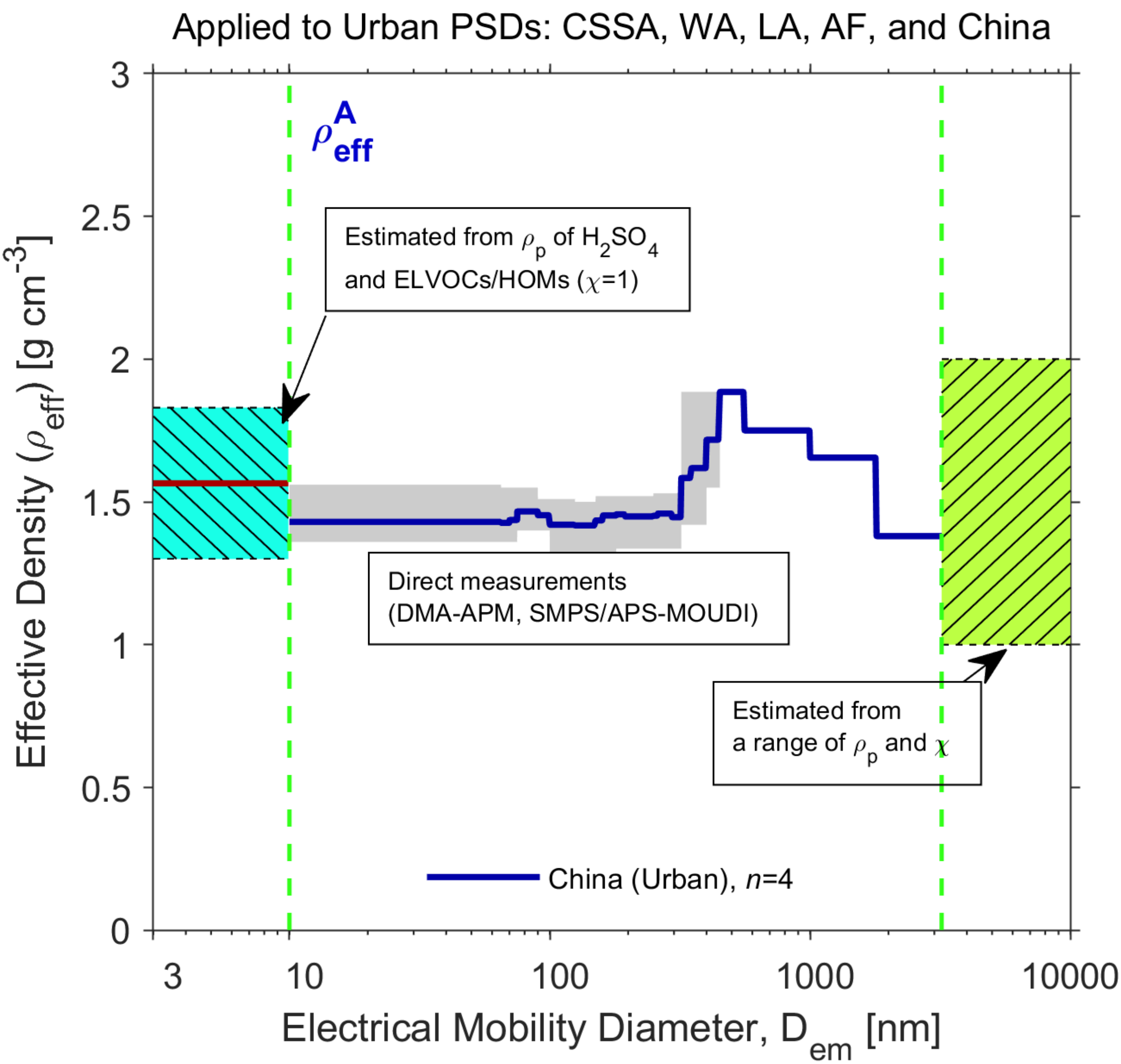
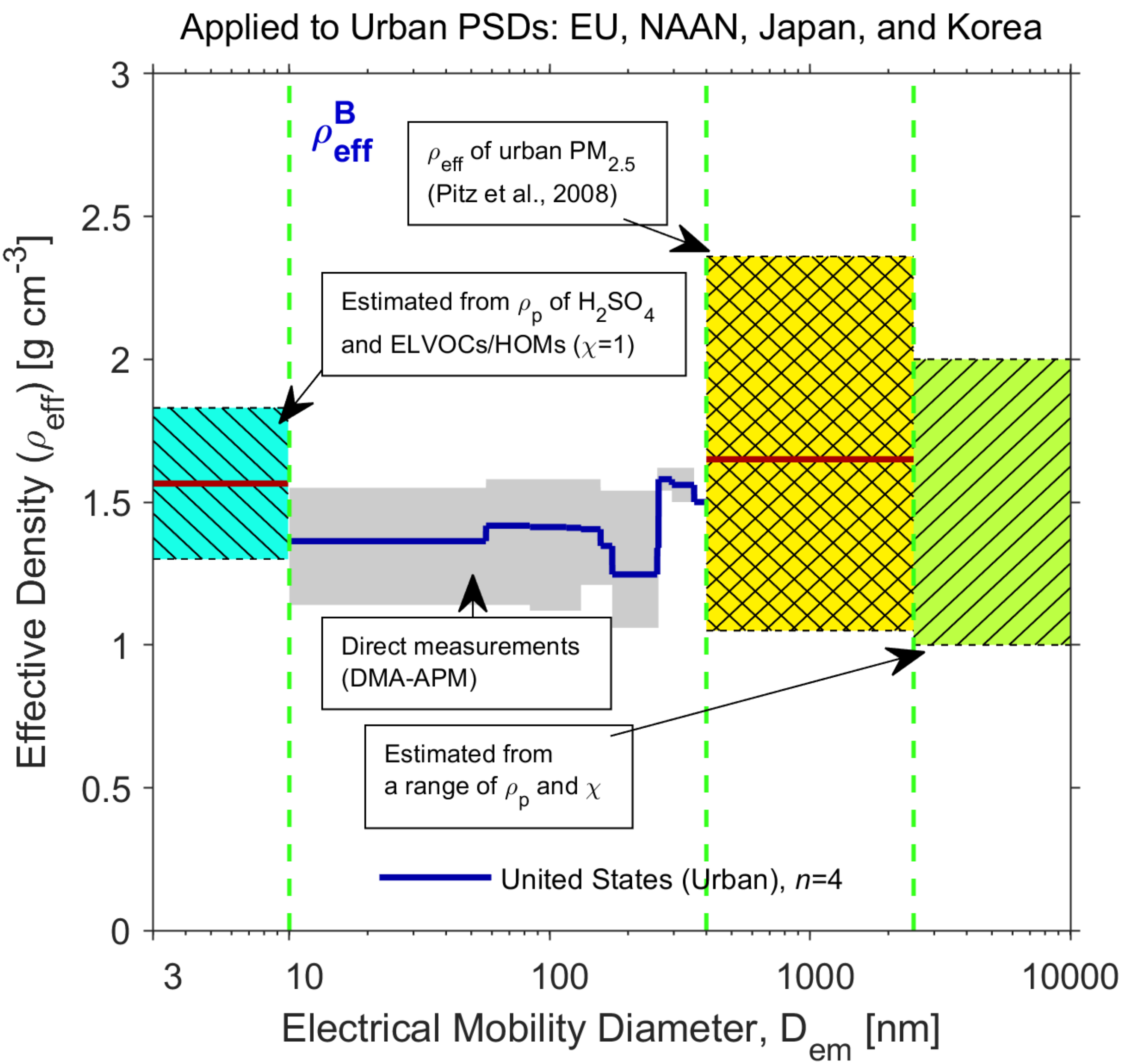


Figure 1. Effective densities (ρ_{eff}) as derived from different values of dynamic shape factors (χ) and particle densities (ρ_p), assuming the value of $\frac{C_c(D_{ve})}{C_c(D_{em})}$ is approximately unity for coarse particles.


Applied to Urban PSDs: CSSA, WA, LA, AF, and China
ρ^{A}_{eff}
Estimated from ρ_p of H_2SO_4 and ELVOCs/HOMs (χ=1)
Direct measurements (DMA-APM, SMPS/APS-MOUDI)
Estimated from a range of ρ_p and χ
China (Urban), n=4
Effective Density (ρ_{eff}) [g cm^{-3}]
Electrical Mobility Diameter, D_{em} [nm]
3
2.5
2
1.5
1
0.5
0
3
10
100
1000
10000

61


Applied to Urban PSDs: EU, NAAN, Japan, and Korea
ρ_{eff}^{B}
ρ_{eff} of urban $PM_{2.5}$
(Pitz et al., 2008)
Estimated from ρ_p of H_2SO_4
and ELVOCs/HOMs (χ=1)
Direct measurements
(DMA-APM)
Estimated from
a range of ρ_p and χ
United States (Urban), *n*=4
Effective Density (ρ_{eff}) [g cm^{-3}]
Electrical Mobility Diameter, D_{em} [nm]
0
0.5
1
1.5
2
2.5
3
3
10
100
1000
10000

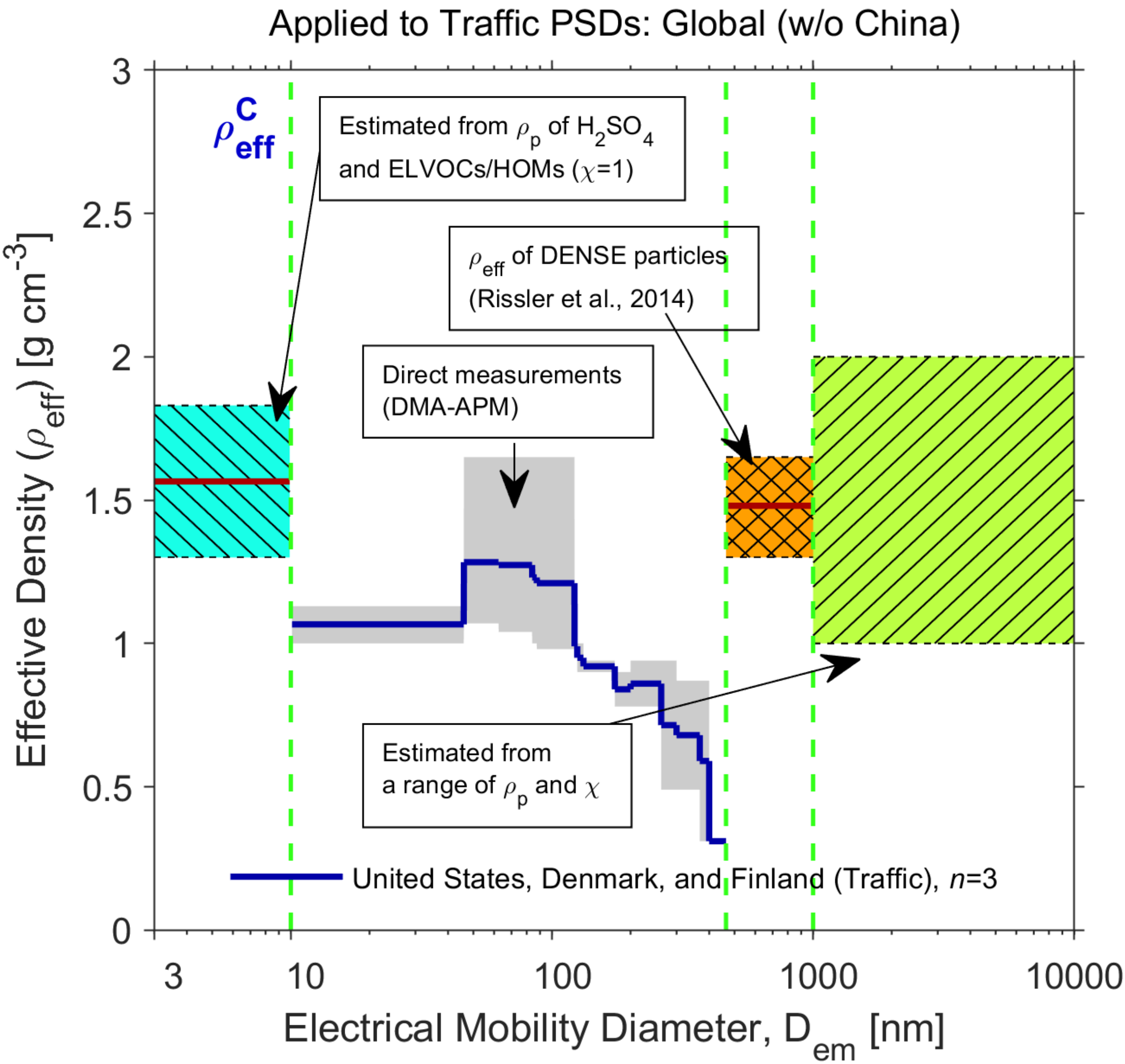
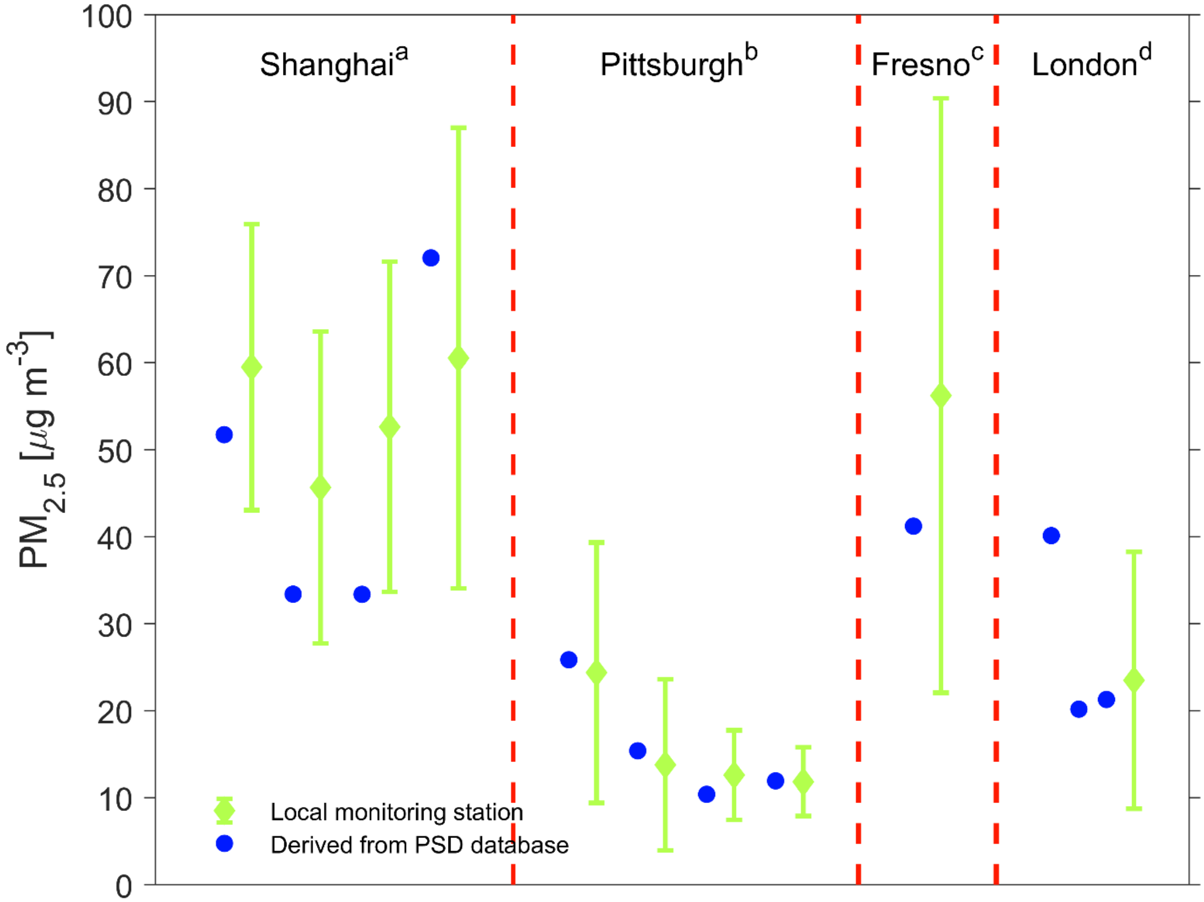


Figure 2. Size-resolved urban aerosol effective density functions (ρ_{eff}) for Group A ('urban'; obtained from measurements in China), Group B ('urban'; obtained from measurements in the United States), and Group C ('traffic'; obtained from measurements in the United States, Finland, and Denmark). Details of the ρ_{eff} measurements are summarized in Table 2. ρ_{eff} values for different combinations of χ and ρ_p are illustrated in Fig. 2. Measurement technique nomenclature: DMA: Differential Mobility Analyzer, APM: Aerosol Particle Mass Analyzer, SMPS: Scanning Mobility Particle Sizer, APS: Aerodynamic Particle Sizer, MOUDI: Micro-Orifice Uniform Deposit Impactor.



[a]PSDs from Ding et al. (2017), $PM_{2.5}$ from Shanghai Environment Monitoring Center at Hongkou Liangcheng Station, including four different sampling periods.
[b]PSDs from Cabada et al. (2004), $PM_{2.5}$ from EPA monitoring station (42-003-0021), including four different sampling periods.
[c]PSD from Watson et al. (2002), $PM_{2.5}$ from EPA monitoring station (06-019-0008).
[d]PSDs from Harrison et al. (2012), $PM_{2.5}$ from UK Automatic Urban and Rural Monitoring Network at London Marylebone Road. Three PSDs were measured at three different sampling sites over the same period.

Figure 7. Comparison of the $PM_{2.5}$ derived from the PSDs collected in this study (blue circular markers) with those measured by local monitoring stations in the same city over the same sampling periods (green diamond markers and error bars). The green diamond markers represent the mean values of the $PM_{2.5}$ from local sampling stations over the sampling period of the corresponding PSD and the error bars represent the standard deviations.

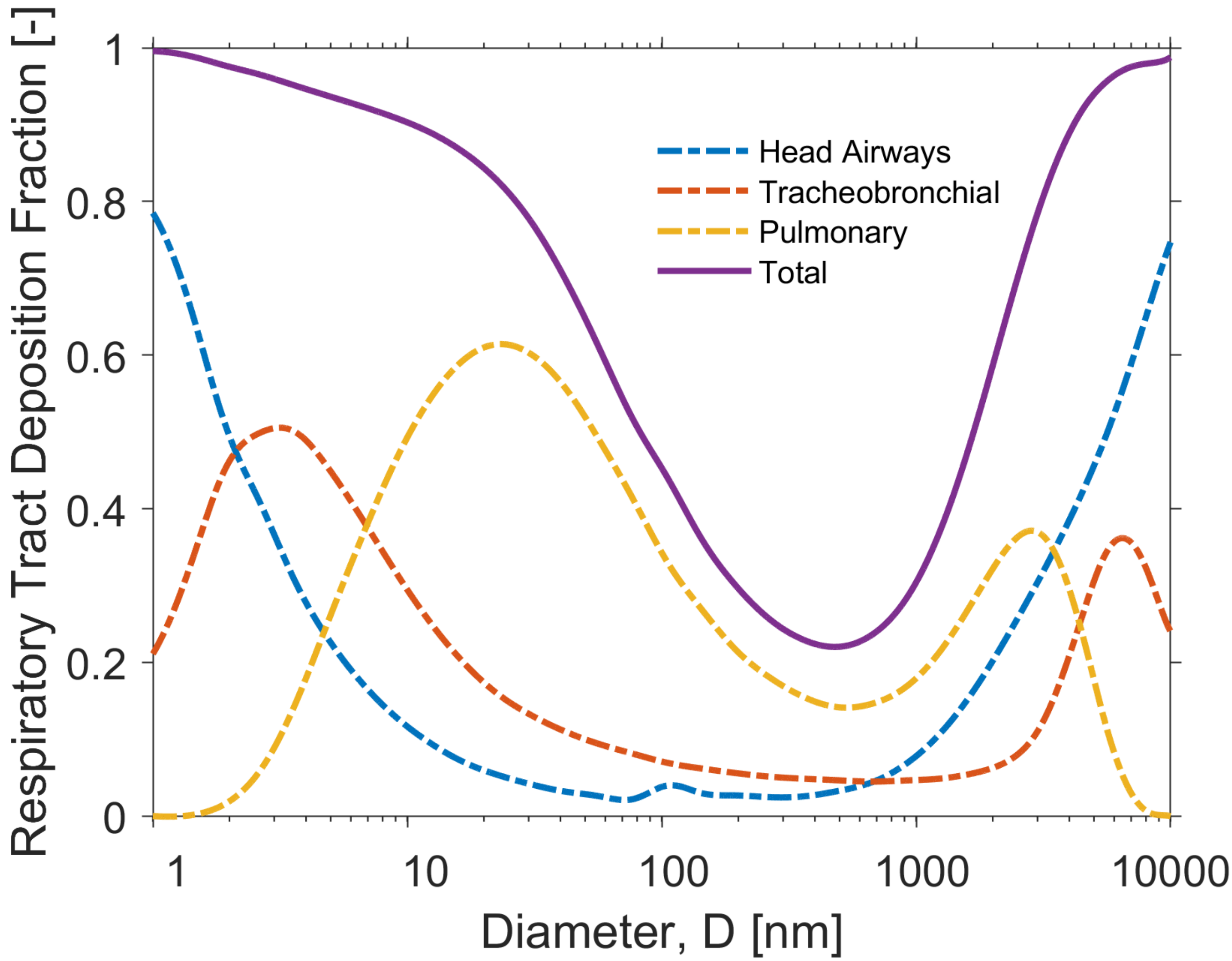


Figure 8. Size-resolved particle deposition fractions in the human respiratory tract, estimated by using the symmetric single-path model from the open-source Multiple-Path Particle Dosimetry (MPPD) Model (v3.04, Applied Research Associates, Inc., Albuquerque, NM, USA) (Miller et al., 2016) for an adult with an upright upper body.

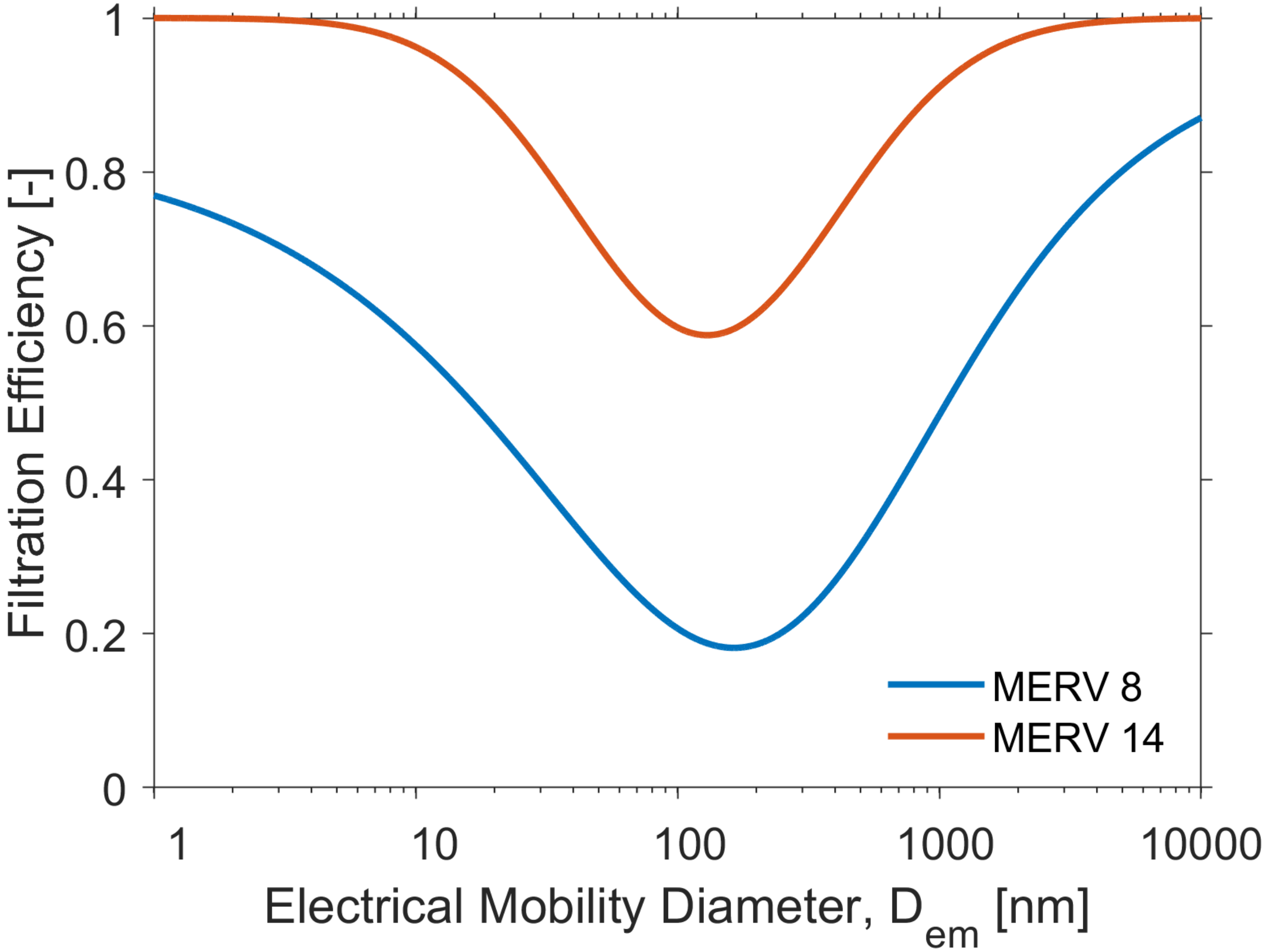


Figure 9. Size-resolved filtration efficiency curves for MERV 8 and MERV 14 filters for estimating the number PSDs of the penetrated urban aerosol (Hecker and Hofacre, 2008).

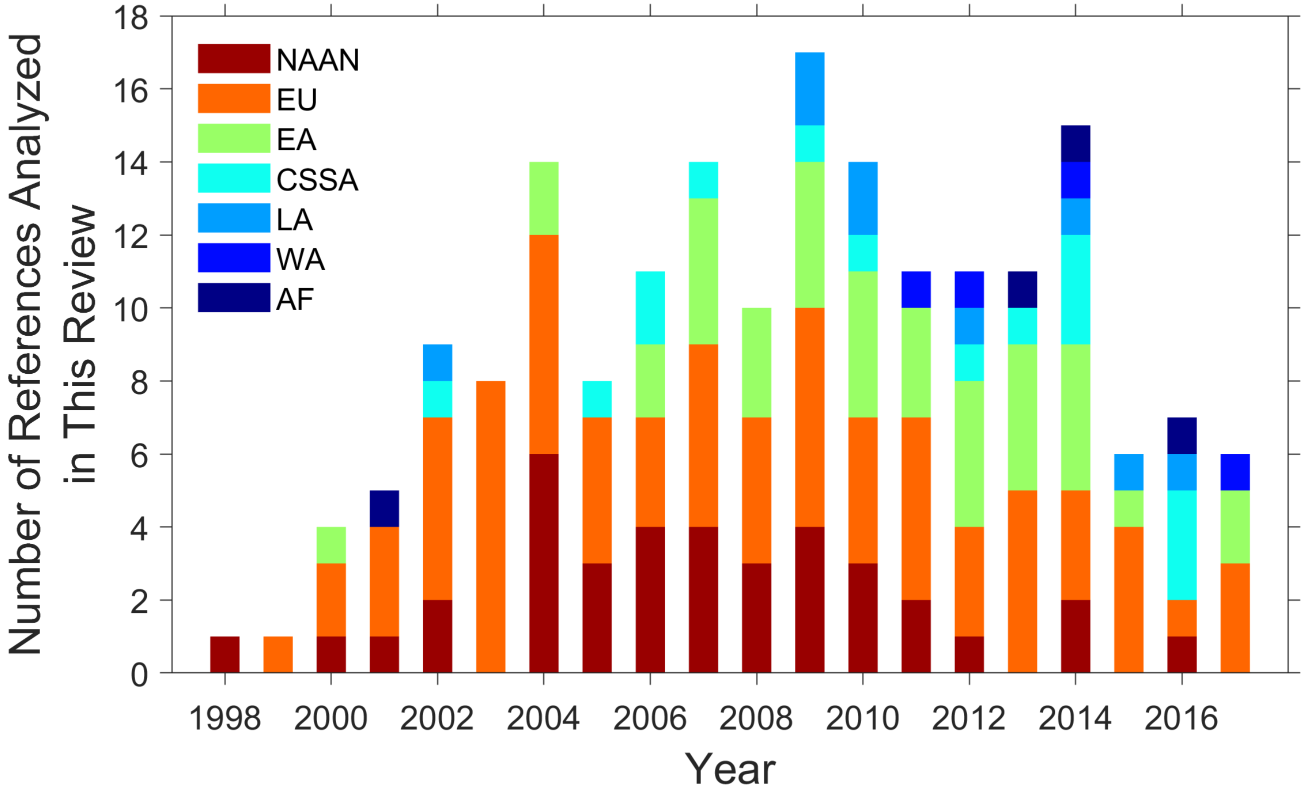


Figure 10. Temporal and geographical distribution by year of the urban PSD references analyzed in this study (1998-2017). The geographical regions include North America, Australia, and New Zealand (NAAN), Europe (EU), East Asia (EA), Central, South, and Southeast Asia (CSSA), Latin America (LA), West Asia (WA), and Africa (AF).

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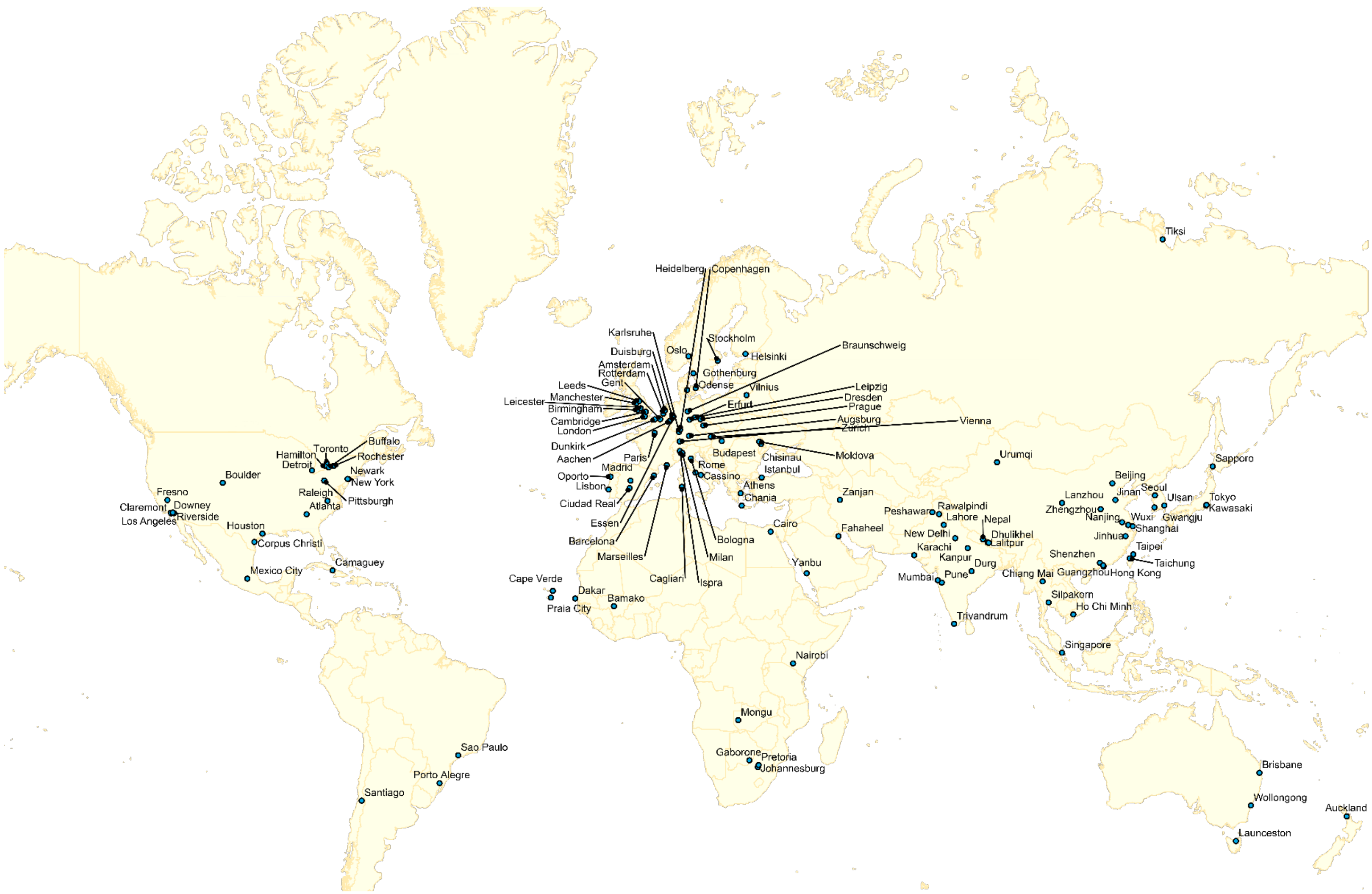


Figure 11. Global distribution of urban aerosol PSD measurement locations included in this study.

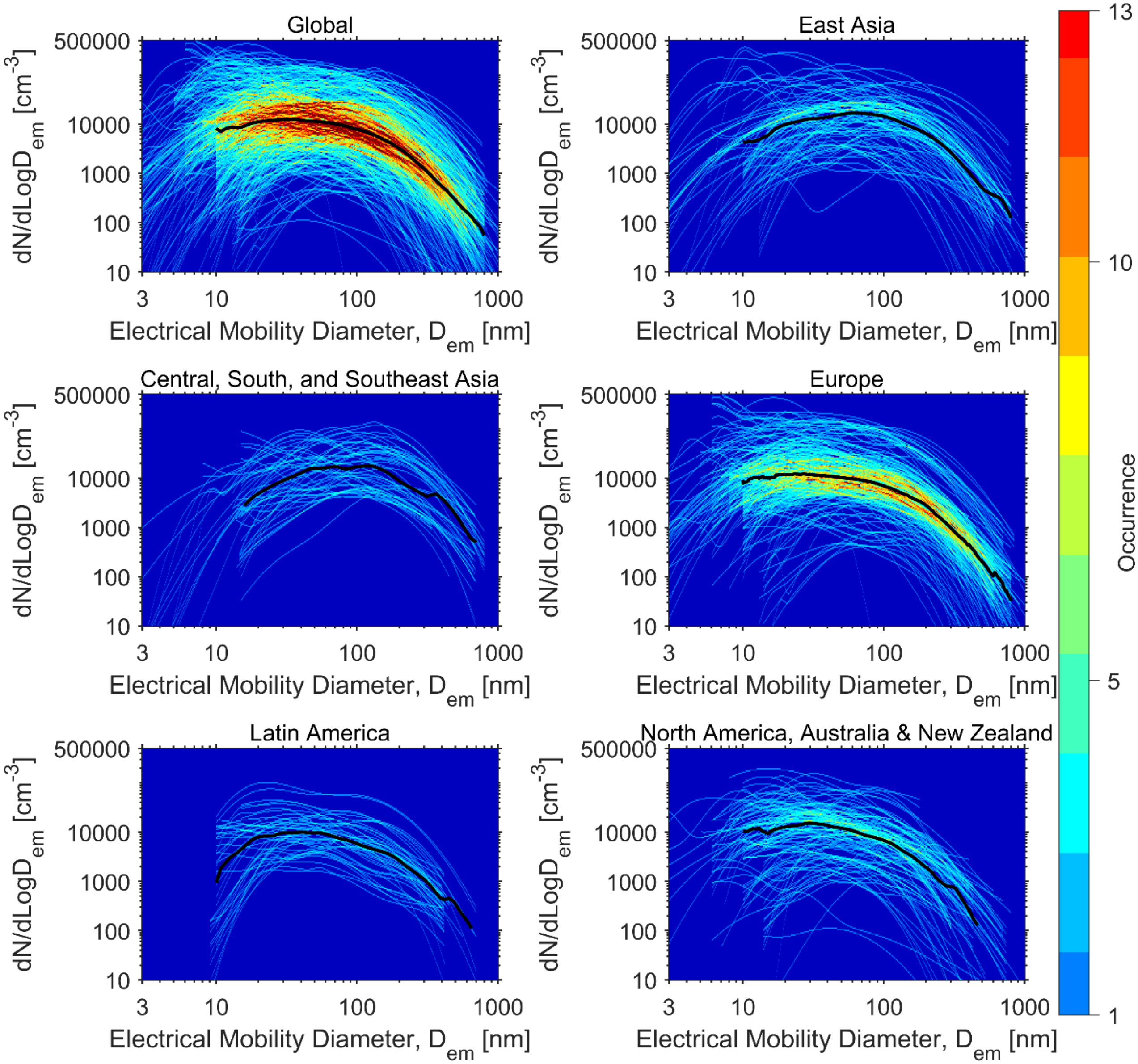


Figure 12. Urban aerosol number PSDs analyzed in this study, grouped by geographical region. The figure incorporates all sub-micron number PSDs measured by electrical mobility-based techniques (n=624). The color represents the occurrence frequency of the number PSDs at a given particle size with a certain concentration. The black lines indicate the median number PSDs in each group.

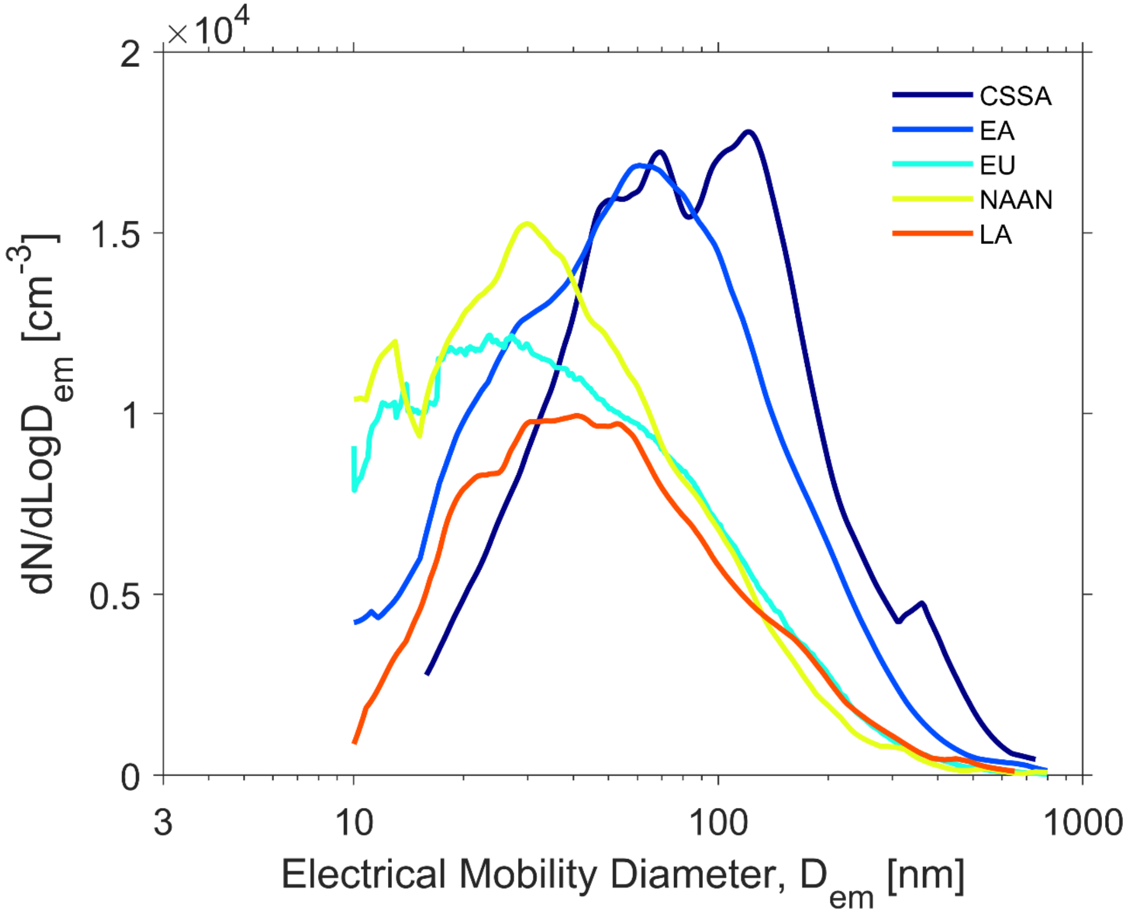


Figure 13. Median number PSDs for each geographical region.

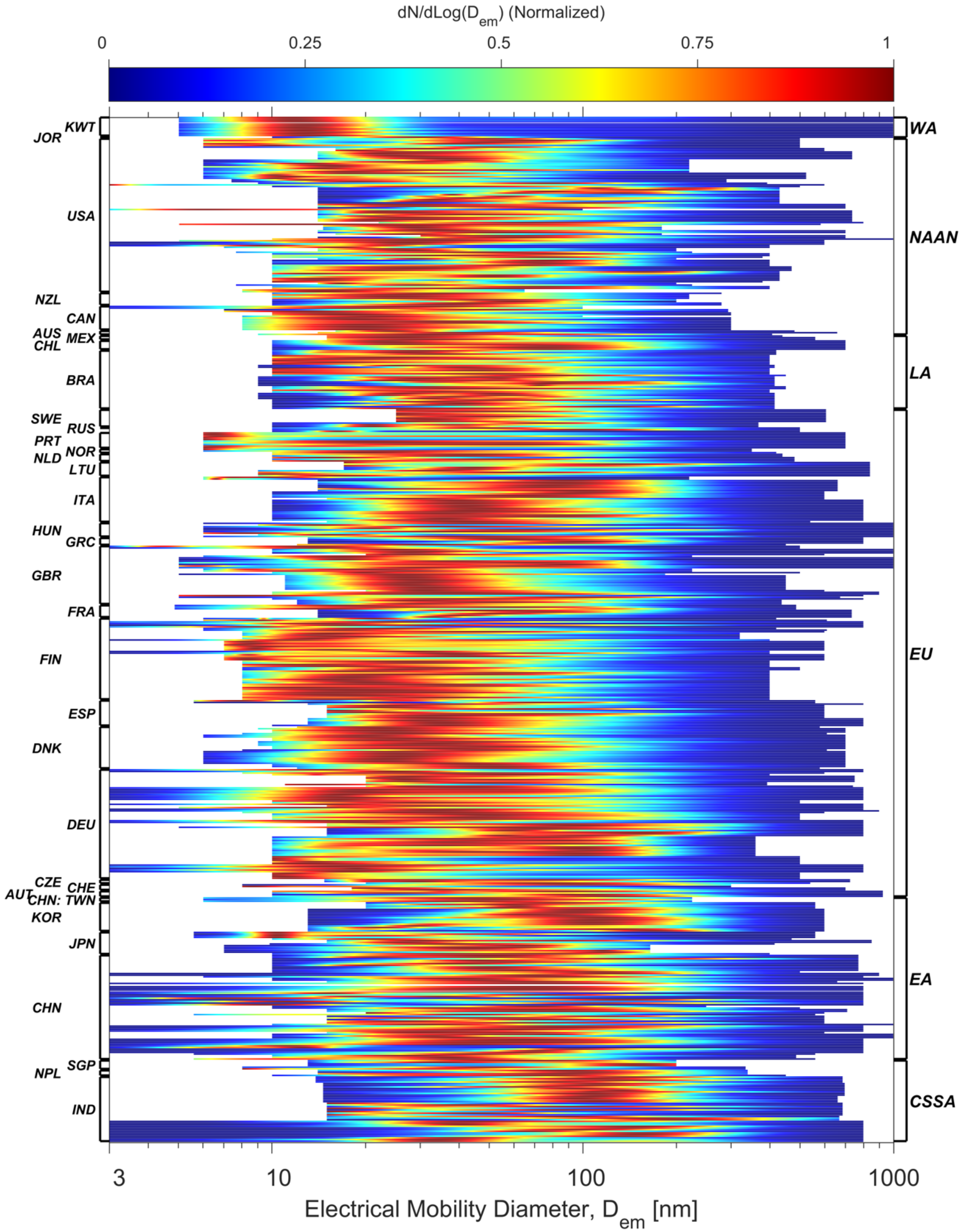


Figure 14. Normalized urban aerosol number PSDs analyzed in this study from around the globe. The country codes are listed on the left and the region codes are listed on the right.

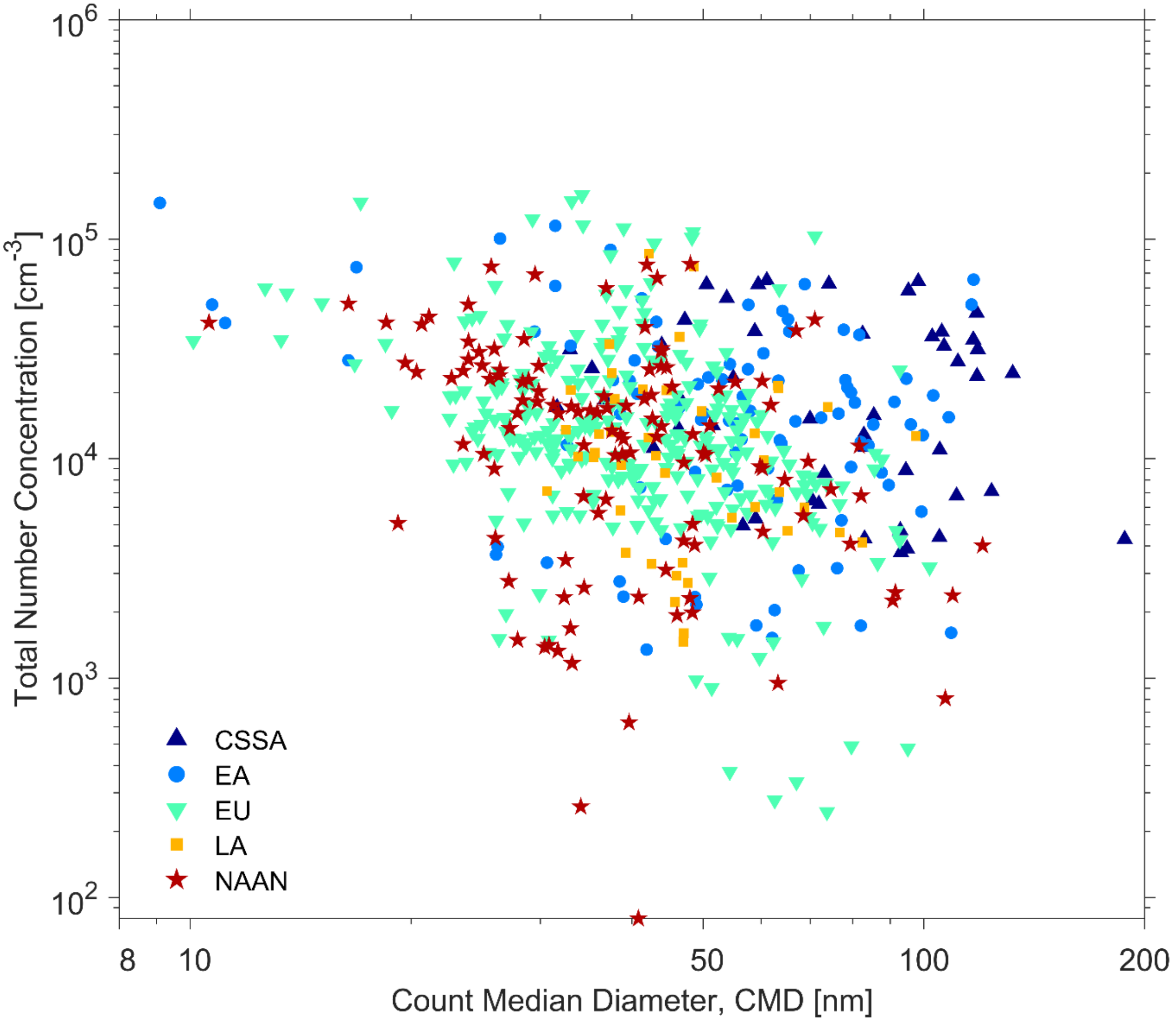


Figure 15. Relationship between the total particle number concentration, integrated over the measured size range, and the count median diameter (CMD), determined for each sub-micron number PSD measured by electrical mobility-based techniques (*n*=624) and grouped by geographical region.

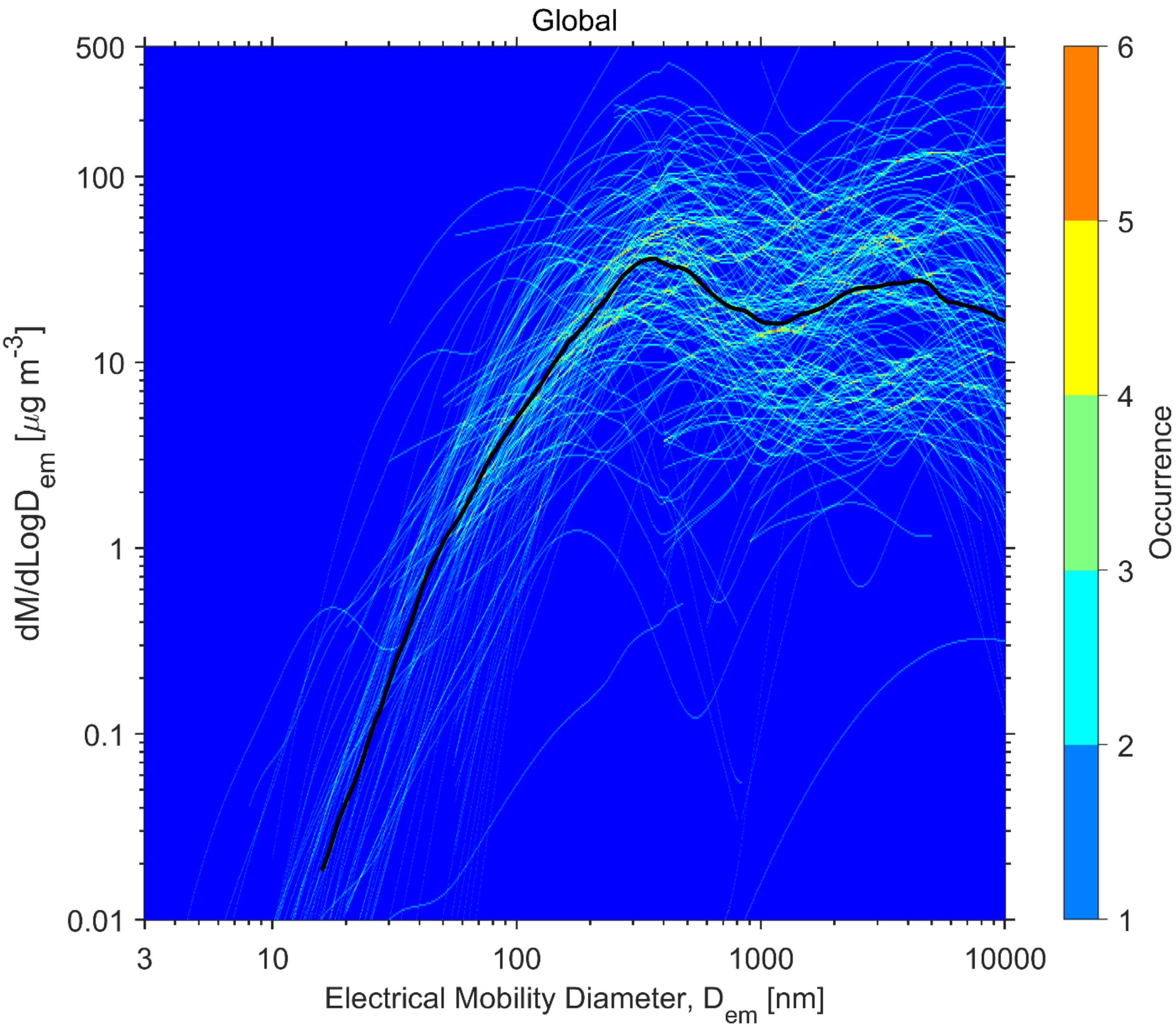


Figure 16. Urban aerosol mass PSDs analyzed in this study from around the globe (n=122). The figure incorporates mass PSDs measured by gravimetric methods with inertial impactors and measurements made with electrical mobility-based and aerodynamic-/optical-based techniques that cover both the sub-micron and coarse modes. The color represents the occurrence frequency of the mass PSDs at a given particle size with a certain concentration. The black line indicates the median mass PSD.

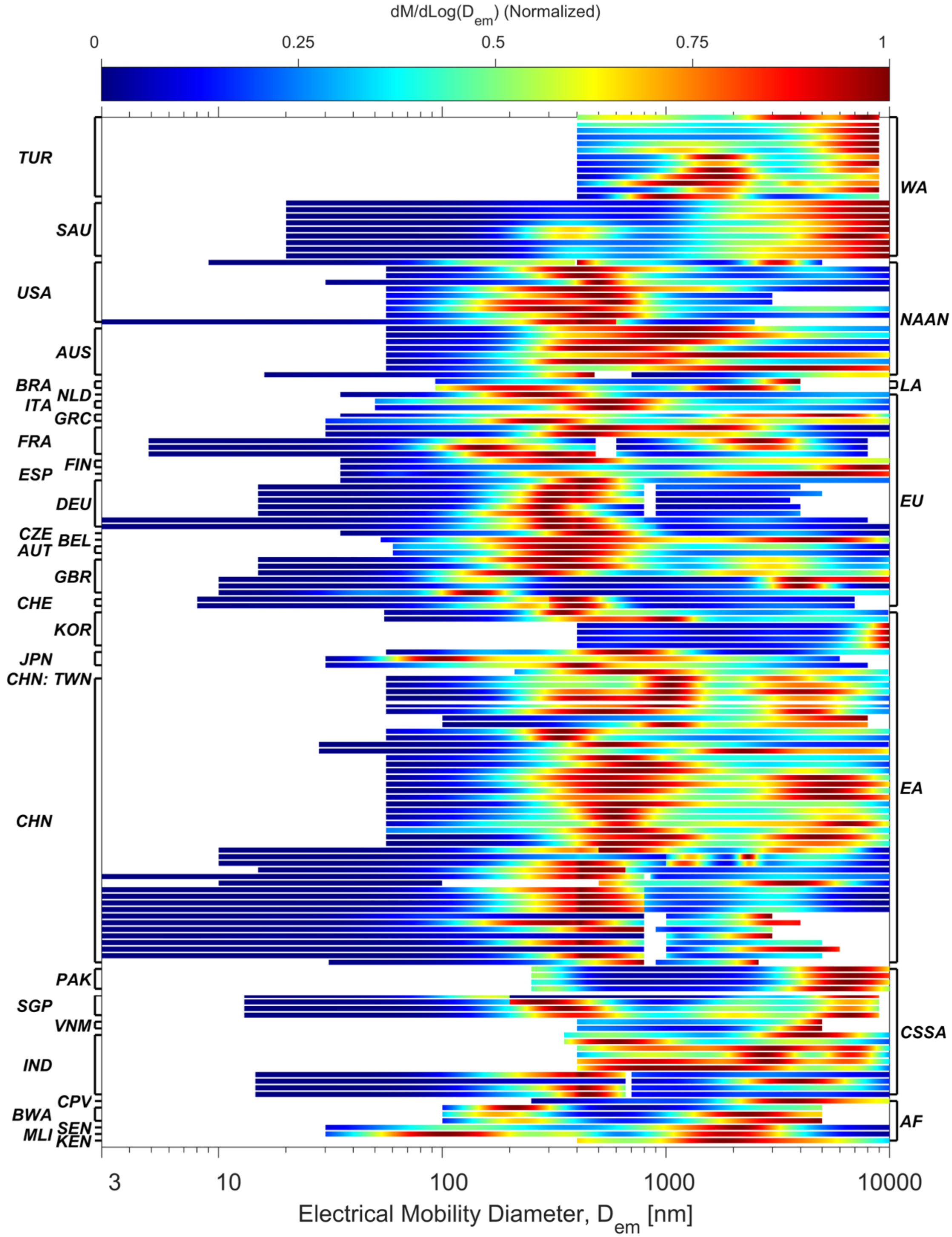


Figure 17. Normalized urban aerosol mass PSDs analyzed in this study from around the globe. The country codes are listed on the left and the region codes are listed on the right.

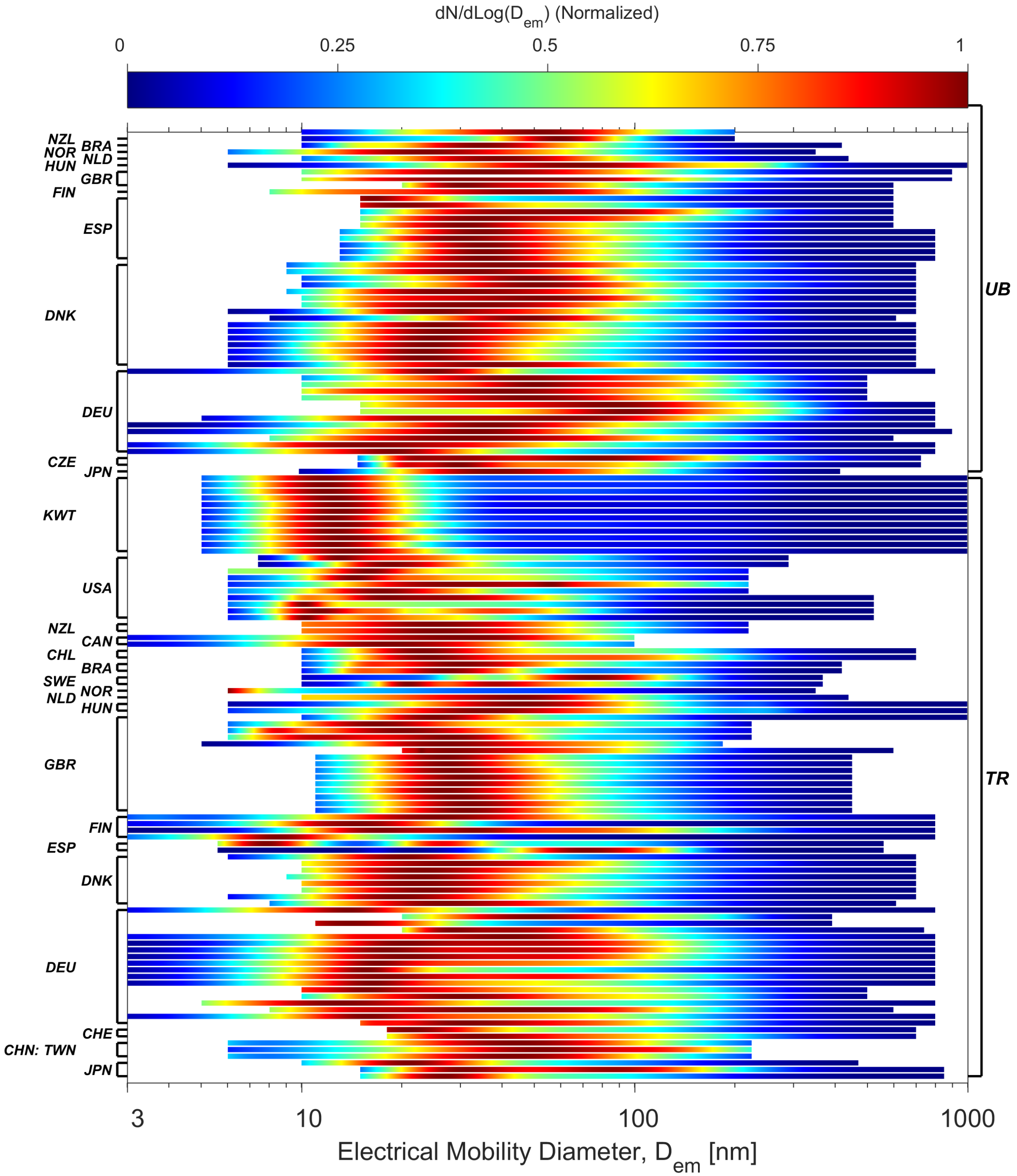
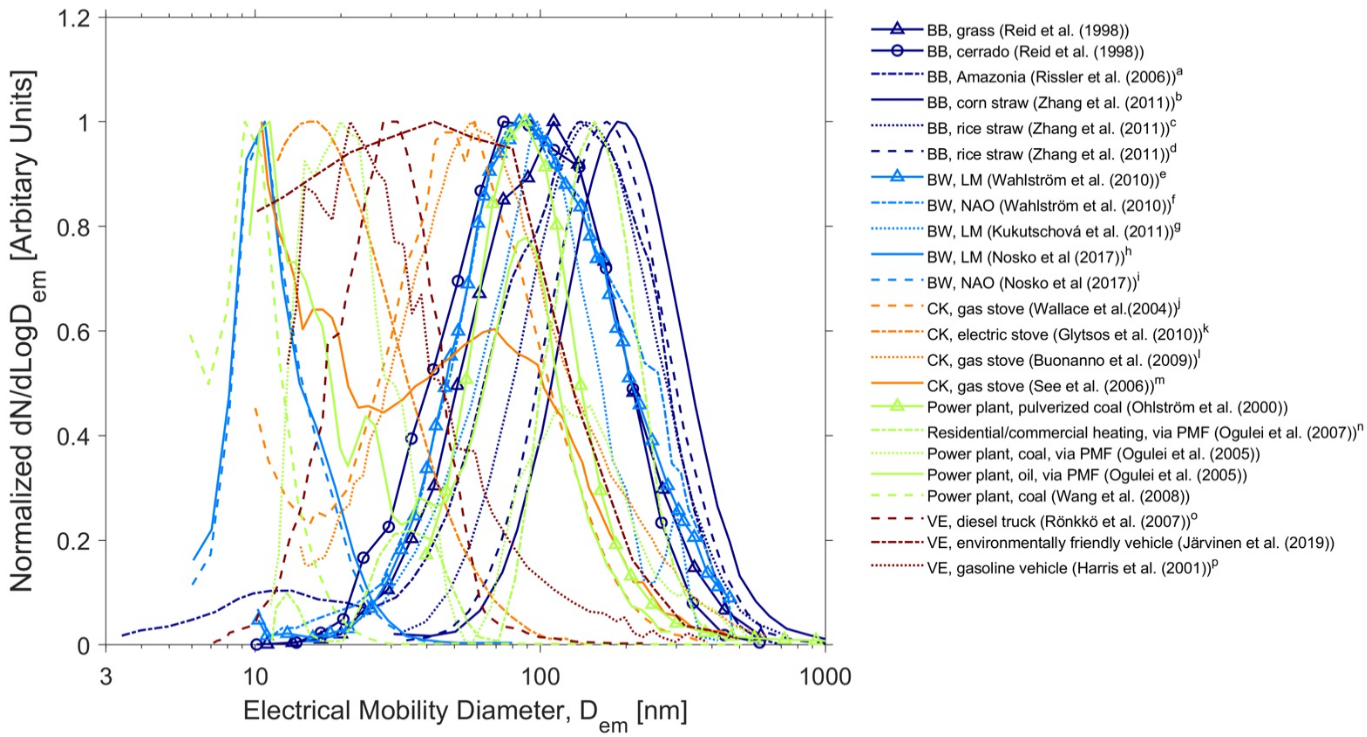


Figure 18. Comparison between normalized urban aerosol number PSDs measured at urban background (UB) and traffic-influenced (TR) sites. Only the number PSDs with a measurement period greater than one week are presented. The country codes are listed on the left and the site type is listed on the right.



[a]Dry period in Fig. 4a in Rissler et al. (2006).
[bcd]PSD after ageing of 30 min in Fig. 6 in Zhang et al. (2011).
[e]LM1 in Fig. 7 in Wahlström et al. (2010). Brake pad material: low metallic (LM).
[f]NAO1 in Fig. 7 in Wahlström et al. (2010). Brake pad material: non-asbestos organic (NAO).
[g]t0+30 min in Fig. 6a in Kukutschová et al. (2011). Brake pad material: LM.
[h]LM 175 °C in Fig. 7 in Nosko et al. (2017). Brake pad material: LM.
[i]NAO 175 °C in Fig. 7 in Nosko et al. (2017). Brake pad material: NAO.
[j]DMA-CPC measurement in Fig. 4 in Wallace et al. (2004).
[k]Frying onion, t=7 min in Fig. 13 in Glytsos et al. (2010).
[l]Grilling bacon with maximum power in Fig. 6a in Buonanno et al. (2009a).
[m]Boiling in Fig. 2a in See and Balasubramanian (2006).
[n]Residential/commercial heating in winter in Fig. 6 in Ogulei et al. (2007b).
[o]Test condition 8 without thermodenuder in Fig. 2a in Rönkkö et al. (2007).
[p]Gasoline engine #2 at 96 km h^{-1} in Fig. 4 in Harris and Maricq (2001).

Figure 19. Normalized number PSDs of selected urban aerosol sources, including biomass burning (BB), brake wear (BW), cooking (CK), coal and oil burning for energy and heating, and vehicle exhaust (VE). Each number PSD is normalized by its maximum concentration.

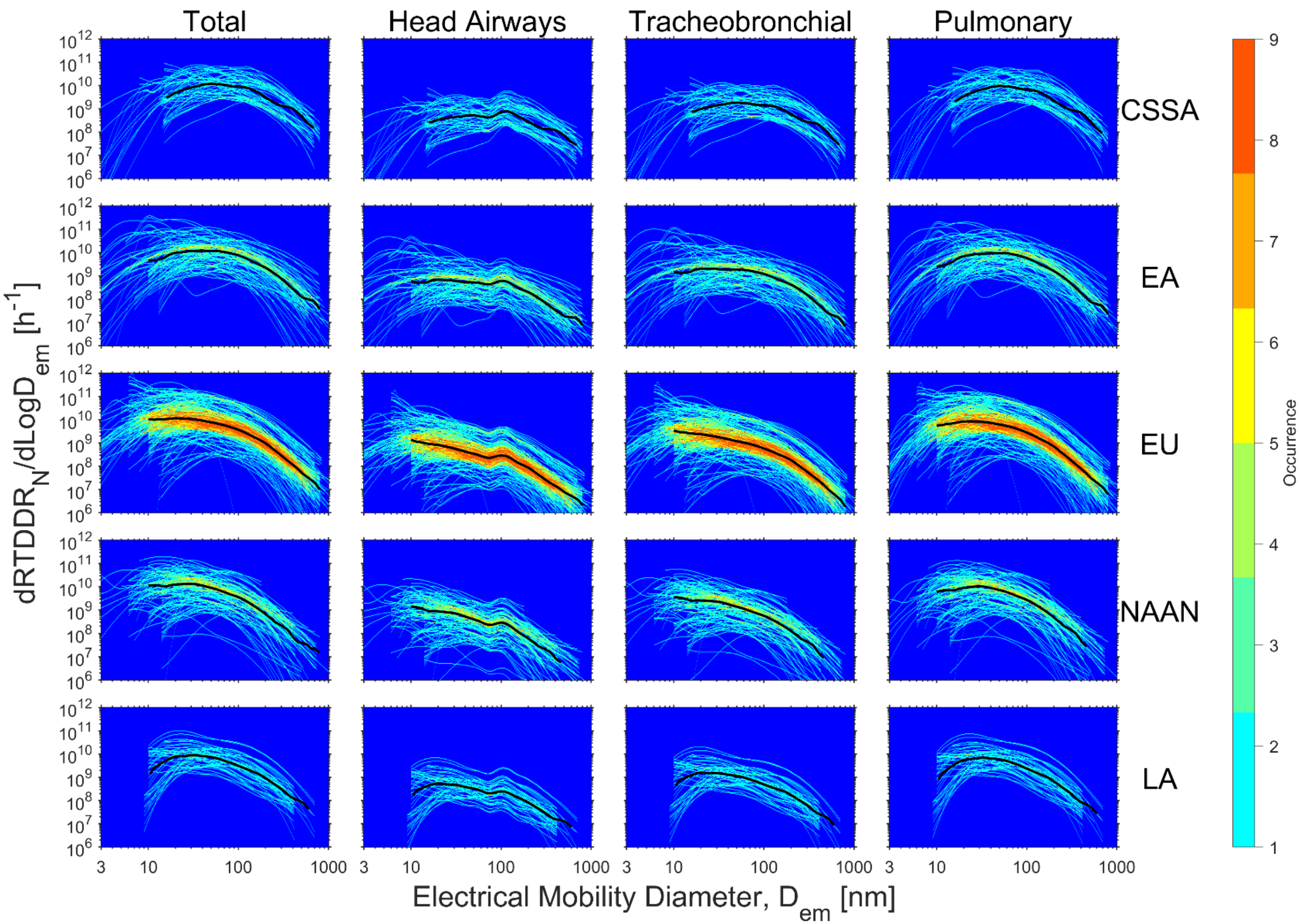


Figure 20. The total and regional $dRTDDR_N/dLogD_{em}$ in the respiratory tract in different geographical regions determined using the urban number PSDs analyzed in this study. The color represents the occurrence frequency of the $dRTDDR_N/dLogD_{em}$ at a given particle size with a certain dose rate. The black lines indicate the median $dRTDDR_N/dLogD_{em}$ in each group.

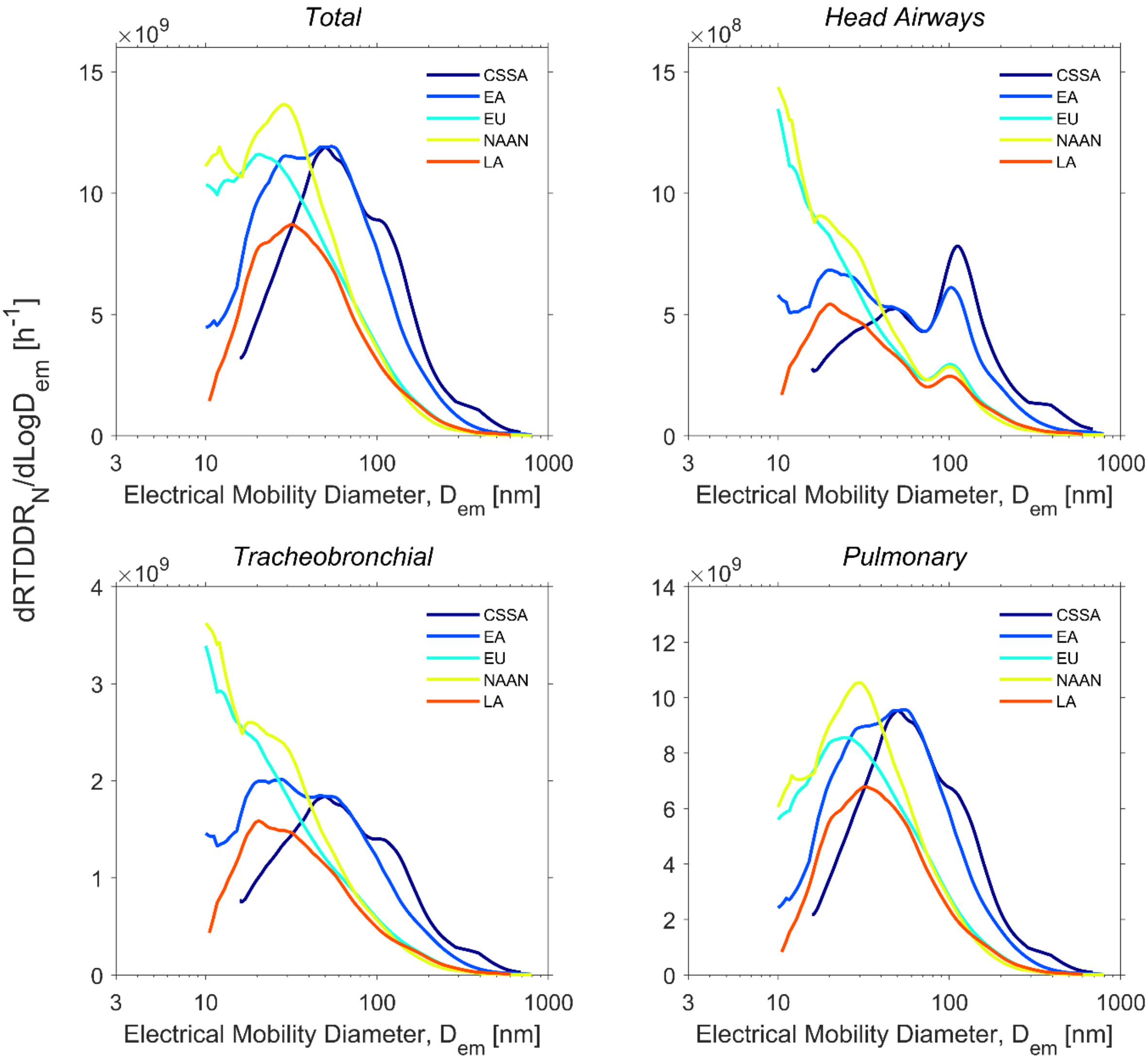


Figure 21. Median $dRTDDR_N/dLogD_{em}$ in each geographical region (black lines in Fig. 19).

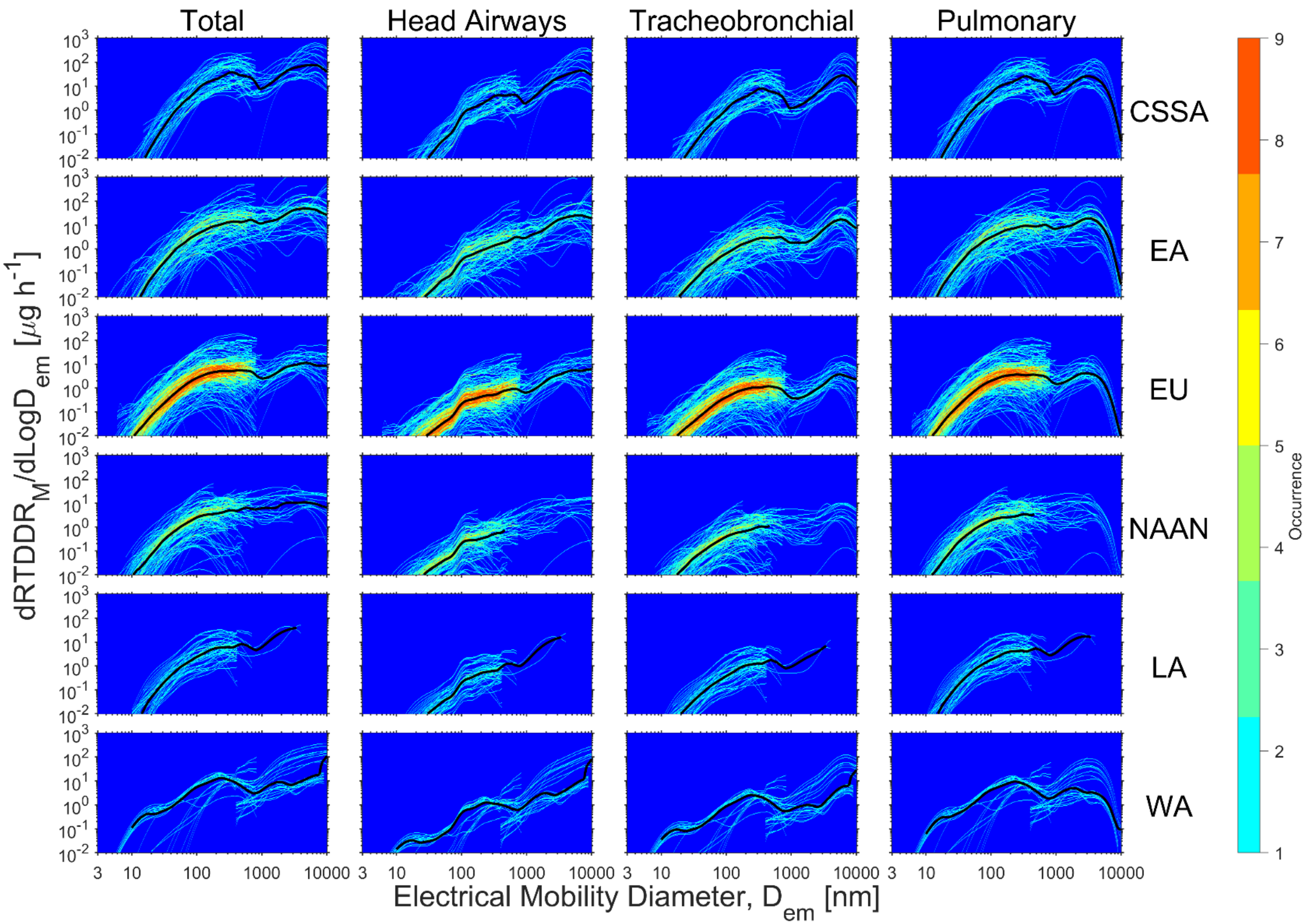


Figure 22. The total and regional $dRTDDR_M/dLogD_{em}$ in the respiratory tract in different geographical regions determined using the urban mass PSDs analyzed in this study. The color represents the occurrence frequency of the $dRTDDR_M/dLogD_{em}$ at a given particle size with a certain dose rate. The black lines indicate the median $dRTDDR_M/dLogD_{em}$ in each group.

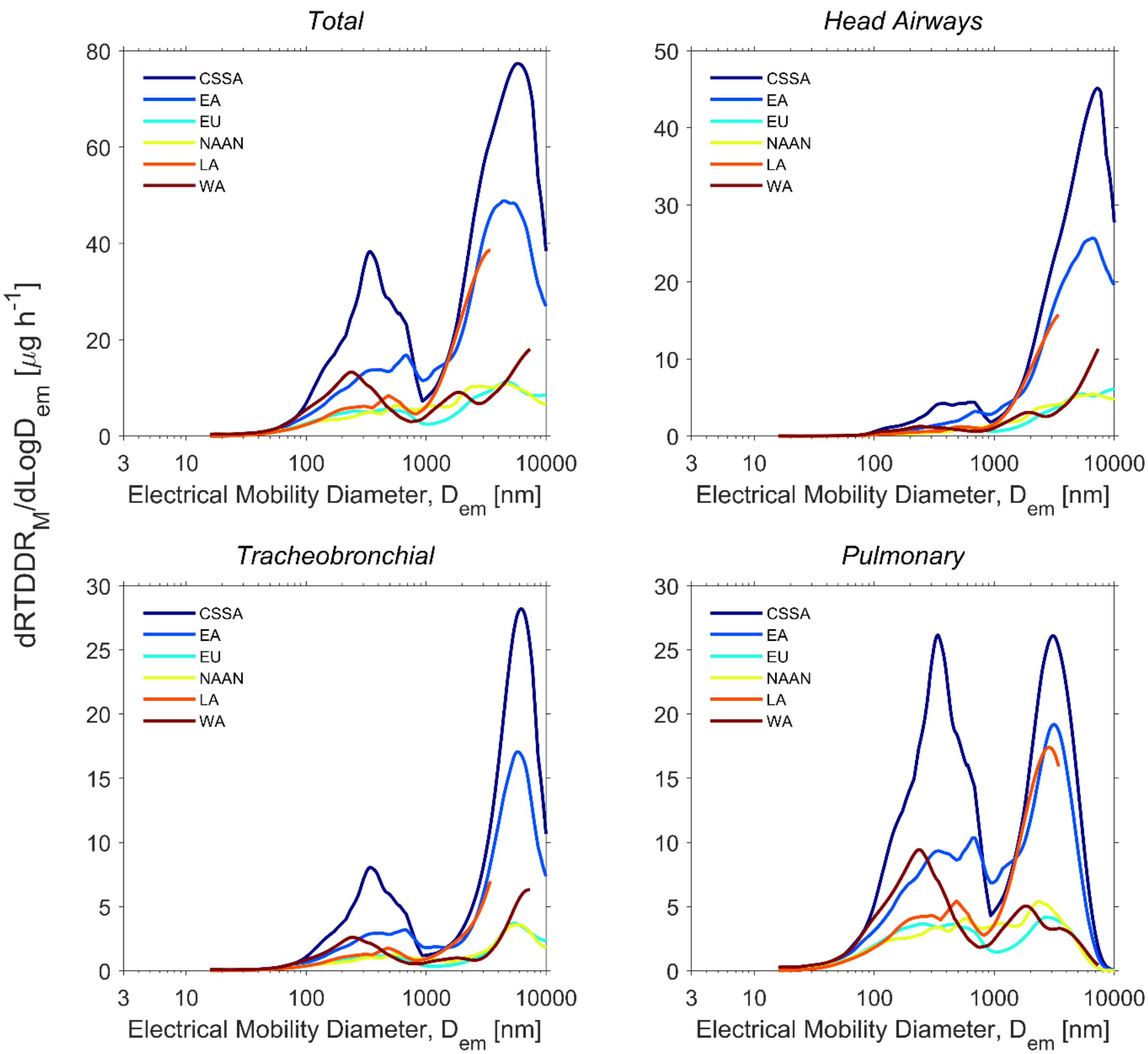


Figure 23. Median $dRTDDR_M/dLogD_{em}$ in each geographical region (black lines in Fig. 21).

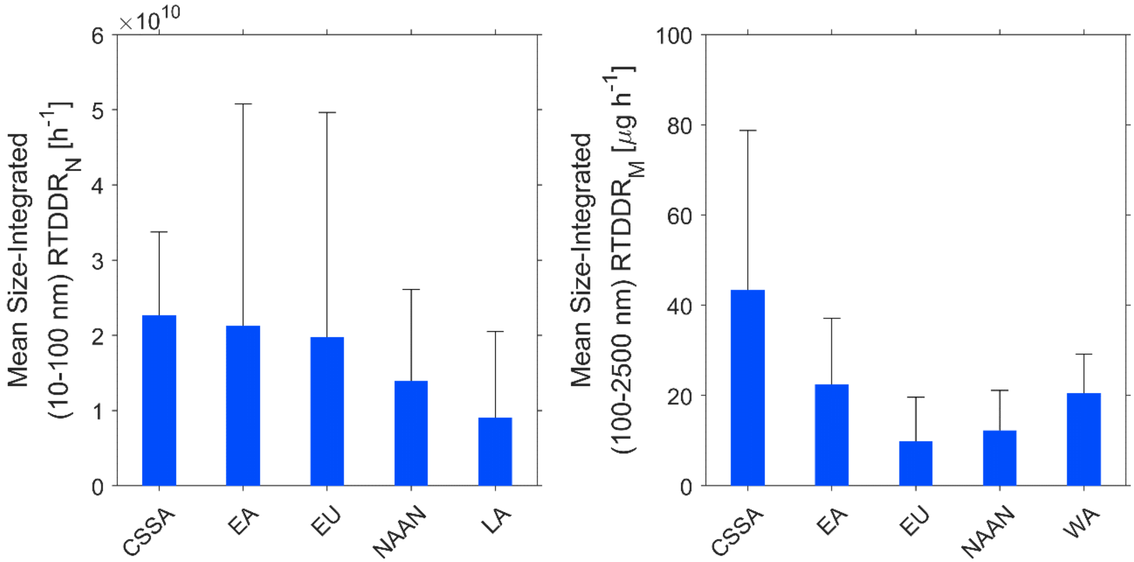


Figure 24. Mean size-integrated (10-100 nm) $RTDDR_N$ and size-integrated (100-2500 nm) $RTDDR_M$ in the respiratory tract in different geographical regions determined using the urban mass PSDs analyzed in this study.

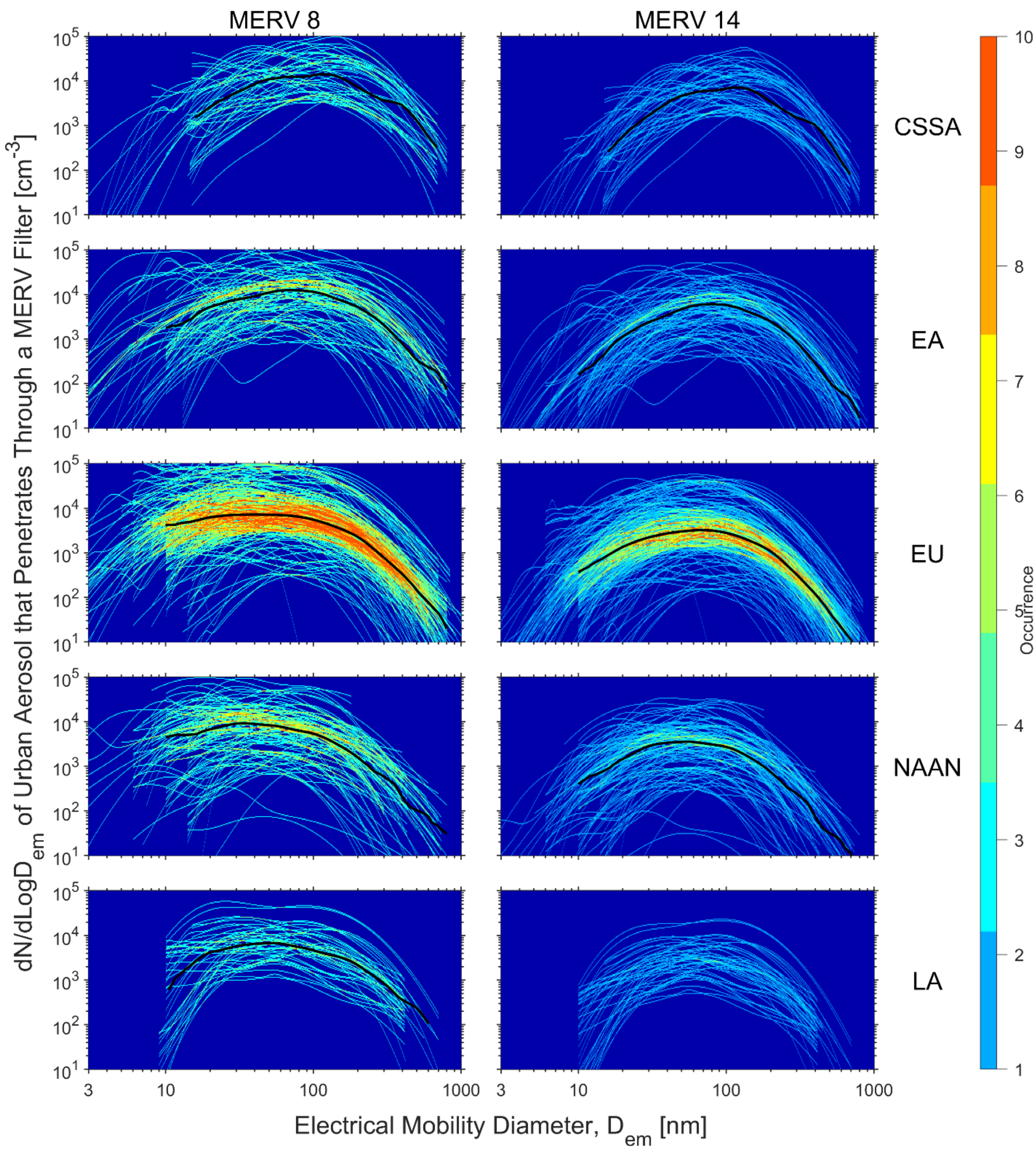


Figure 25. Urban aerosol number PSDs that penetrate through a MERV 8 and 14 filter in a building ventilation system for each geographical region, estimated using the number PSDs collected in this study (Fig. 11) and assuming single-pass MERV 8 and MERV 14 filters. The color represents the occurrence frequency of the penetrated number PSDs at a given particle size with a certain concentration. The black lines indicate the median penetrated number PSDs in each group.

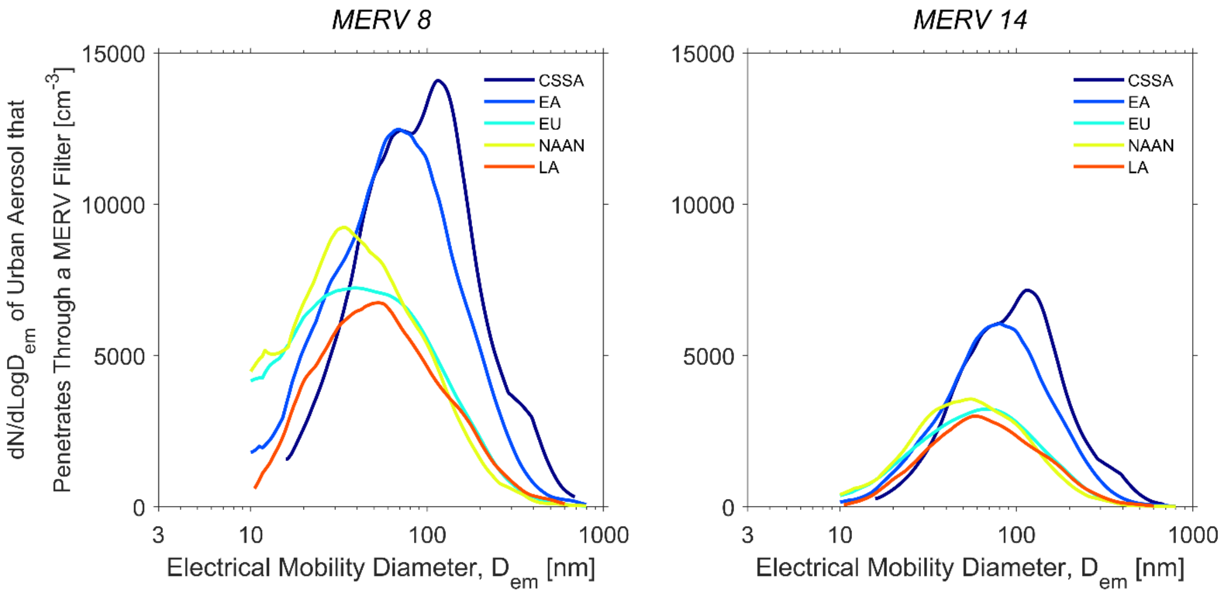


Figure 26. Median urban aerosol number PSDs that penetrate through a MERV 8 (left) and a MERV 14 (right) filter in a building ventilation system for each geographical region (black lines in Fig. 23).

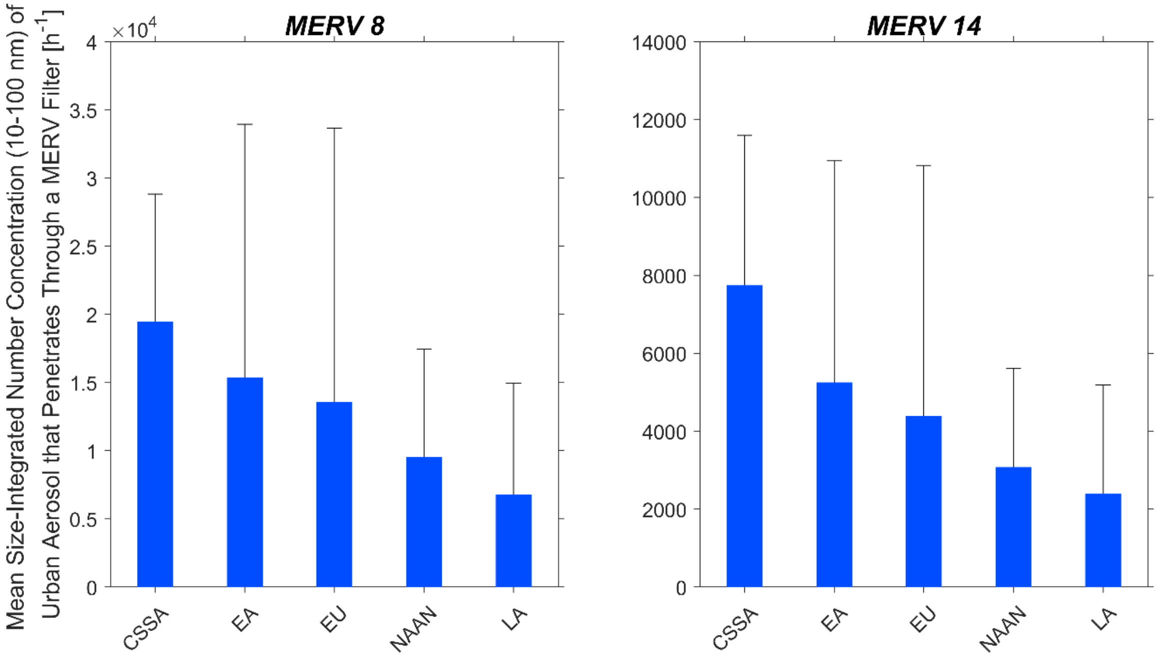


Figure 27. Mean size-integrated number concentration (10-100 nm) of urban aerosol that penetrate through a MERV 8 (left) and a MERV 14 (right) filter in a building ventilation system for each geographical region.

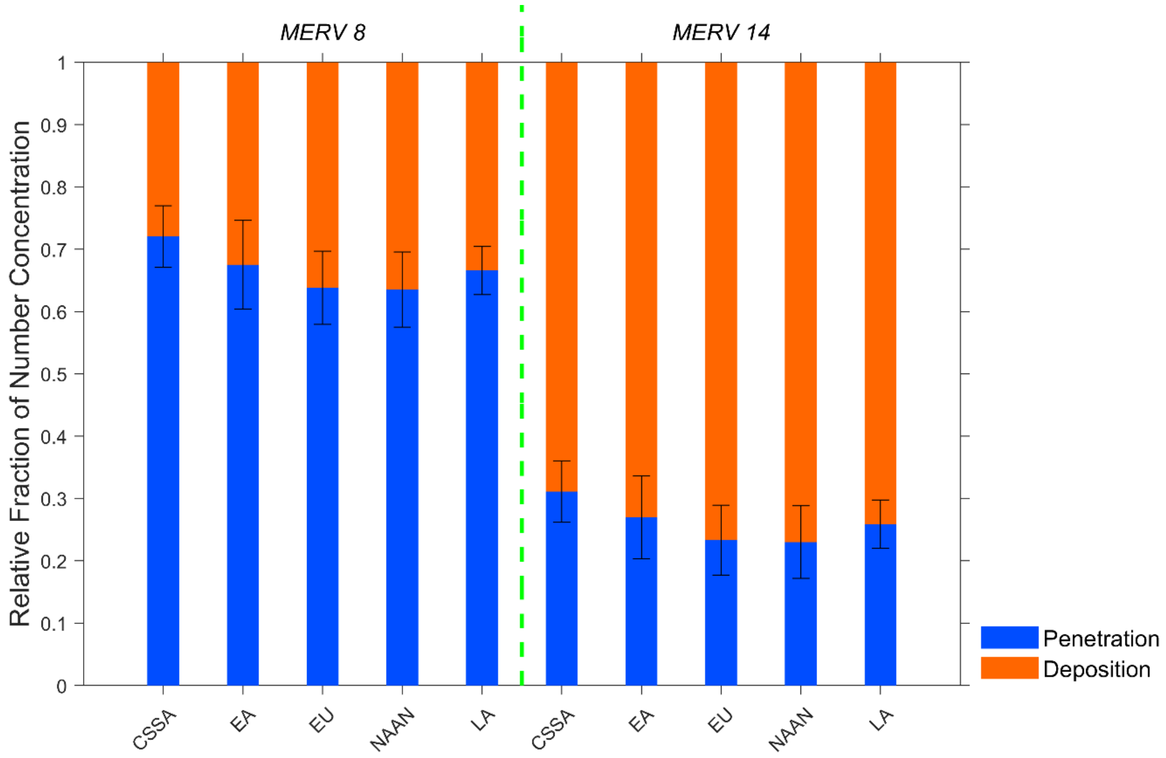


Figure 28. Mean HVAC filter penetration and deposition fractions for each geographical region, assuming single-pass MERV 8 and MERV 14 filters.